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New and spectacular developments, such as the generation of electricity from nuclear energy and automatic control of production, have created the impression that we are going through a new industrial revolution. Closer examination of the facts suggests that the present striking changes are the result of an evolutionary process which had its roots in the second half of the eighteenth century. We are now in the third phase of the Industrial Revolution, in which the complexities of discovery and invention have grown to such an extent that they have raised social, psychological and organizational problems which, in turn, are exerting their influence on the development of industry. In this third phase, the social sciences have perhaps a more important role to play than the natural sciences and technology themselves.

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SCIENCE AND THE CHANGING FACE OF INDUSTRY—THE SOCIAL PHASE

by

ALEXANDER KING

Dr. King is a physical chemist whom the war drew from research into government, first as Deputy Scientific Adviser to the British Ministry of Production, then as Scientific Attaché and head of the U.K. Scientific Office in Washington. He later became the first head of the Scientific Secretariat of the Office of the Lord President of the Council, and is now Chief Scientific Officer in charge of the Intelligence Division of the Department of Scientific and Industrial Research. He is also Chairman of the Productivity and Applied Research Committee of the European Productivity Agency (OEEC).

Much has been heard lately about 'the new Industrial Revolution', and new and spectacular developments—the generation of electricity from nuclear energy, and automatic control of production—explain and justify the use of such a term. The president of one of the great chemical corporations of the United States estimated recently that half the working force of that country is today engaged in producing and selling goods unknown 50 years ago. He forecast that if the present trend were to continue, half the working population 25 years hence would be similarly concerned with products as yet unknown. This acceleration of technological change is no doubt most clearly recognizable in the countries most advanced industrially, but it is a general world trend already affecting every nation, directly and indirectly, and at an ever-increasing pace.

Closer examination of this growing impact of science on industry suggests that there has never been any real discontinuity of development, but rather that the present striking changes are the result of an evolutionary process which had its roots in the early days of the Industrial Revolution in the second half of the eighteenth century.

THE THREE PHASES

It is commonly assumed that the Industrial Revolution was brought about by a sudden rise of modern science. In fact, most of the significant steps of technological progress were made long before the scientists were able to explain the basic nature of the new inventions. Thus, the fundamental improvements in the manufacture of iron and steel made in the eighteenth

century preceded the chemist's discovery of the real differences between steel, wrought iron and cast iron. Similarly, the advancement of theoretical science had little influence on Watt's development of the steam engine.

Practical technological experience had gradually been accumulating for centuries: knowledge of how to extract colouring matter from plants to dye cottage woven cloth, how to make soap, glass and gunpowder, how to mill grain, tan leather and obtain metals from their ores. By the middle of the eighteenth century knowledge of materials and processes had grown to such an extent that each new invention in its turn made possible other advances. For example, the new textile machines invented by Arkwright, Crompton and others led to the abandonment of cottage spinning and to the creation of cotton mills situated on the banks of mountain streams from which they drew their power; in addition, they focused interest on the need for greater and more reliable sources of power. Watt's steam engine, which demanded for its manufacture improvements in iron making and engineering, was soon put to use to produce the blast for the iron furnaces. Likewise, this engine, in achieving Watt's original objective of greatly increasing the efficiency with which water was pumped from the coal mines, enabled coal production to expand, thus making possible a great rise in the production of iron. So rapid was this cross-fertilization of inventions that in England more patents were granted in the 25 years following 1760 than in the previous century and a half.

Although the first phase of the Industrial Revolution was one of empirical invention, it was greatly stimulated by the spirit of experimentation, characteristic of the time, which also had a revolutionary influence on the techniques and concepts of science. There was, in fact, a close friendship and intellectual exchange between the inventors and the scientists of the period, and even if the latter were not to see the practical applications of their experiments, their ideas spurred on invention.

As the nineteenth century opened, industry in England, and later in Germany, was fast expanding. Based on cheap coal, it was motivated by purely commercial aims which obscured that strange mixture of intellectual curiosity and humanitarianism which had marked some of the earlier entrepreneurs. Vestiges of the industrial society, which then arose, still abound in the drab colliery and mill towns of Western Europe; but the squalor, exploitation and harshness inherent in the new system contained the germ of movements which later led to universal suffrage, general education and the high material standards which the industrially advanced countries enjoy today.

Meanwhile science was developing rapidly, but for a time it had little direct effect on industry. The nineteenth century saw a great enlargement in the content and scope of the fundamental sciences, such as chemistry and physics, which later enabled them to assume a dominant role in industrial

development. Scientific research necessarily became a profession instead of an activity appealing to the enthusiastic amateur, and for a time its main preoccupation was with the discovery of new fundamental knowledge rather than with its application. Indeed, there was a distinct coolness between the academic research worker and the practical industrialist, each abusing the other. In a characteristic passage Count Rumford describes the defensive attitude of the self-satisfied manufacturer of that period: 'Those who are engaged in arts and manufactures are seldom disposed to ask, or even receive, the advice of men of science of whose knowledge they seldom entertain any very high respect. Intent only on acquiring wealth, all their views are confined to that single object.'

Academic scientists of the time were hardly more lenient in their attitude towards industry and towards those of their colleagues whom they considered to have prostituted their learning for commercial ends. Nothing in the history of science is more scathing than Clerk Maxwell's disdain of Graham Bell for his invention of the telephone, even more on the grounds of it being intellectually commonplace than because it was a commercial proposition. Academic snobbery of this type is not yet dead in some of the Western European countries. Although it has not assisted in increasing the scientific content of industry, it has helped to build and maintain the present high standards of European fundamental research by attracting a very large proportion of first-class research minds to an academic career. In the United States the position is, if anything, an inversion of this snobbery, with the result that perhaps too many of the most brilliant scientific workers are attracted to industry. Both sides are now trying to establish a reasonable balance between the fundamental and the applied fields.

Towards the end of the nineteenth century science and industry began to come together again. The electrical industry was the first to be constituted on a basis of fundamental discovery; soon afterwards, the chemical industries began to produce a great variety of materials which had their origin in the laboratory. The fundamental sciences had, in fact, reached a state of maturity which enabled their hypotheses and concepts to be applied to the creation of new materials, new processes and whole new industries. In the case of organic chemistry, for example, the beginning of the present century saw an elaboration of techniques which made possible the synthesis of thousands of compounds, most of them totally unknown in nature; these compounds, possessing new and useful properties, created the basis for the dyestuffs, explosives, plastics, chemo-therapeutic and synthetic fibre industries, which are of great importance for world economy—and in our daily lives. This second phase only became possible when the basic sciences had themselves developed sufficiently to reach the stage of application. This process is still operating today, and with increasing momentum. But since the second world war a new factor has superimposed itself: the complexities of discovery and inven-

tion have grown to such an extent that they have raised social and organizational problems which, in turn, are exerting their influence on the development pattern of industry. This constitutes the third and present phase of evolution.

SCIENCE AND WAR

The two world wars have had a profound influence on the industrial use of science. In the first, the Allies soon found that they had relied unwittingly on the German chemical industry; they had to set to and make arrangements for the manufacture of explosives, drugs, etc. which had hitherto been imported. Germany and her allies, on the other hand, were able to rely on synthetic products; indeed, cut off as they were from sources of natural nitrates, they could only wage a prolonged war thanks to the Haber process for the synthesis of ammonia.

In the second world war the dominant technology was based on physics rather than chemistry. The magnetic mine and the protective devices against it, the magnetron valve and microwave radar, the jet engine, guided air weapons, the proximity fuse, and finally the atomic bomb, were all products of the type of complex applied physics which, called into being by modern warfare, will also have strong repercussions on the shape of peacetime industry. Modern aircraft, television, electronic instrumentation and the generation of electricity from nuclear energy, all owe their present high state of elaboration to the impetus of war. On the chemical side, penicillin, the pioneer of the microbiological warfare against disease, and DDT with its influence on public health and agriculture, follow the same pattern.

One of the most striking developments of the war was the application of scientific method to whole complex situations through the techniques which became known as operational research. In Great Britain, and later in the U.S.A., small groups of scientists were appointed as operational research advisers to various commands of the armed forces. By describing situations accurately and, as far as possible, in quantitative terms, formulating exact problems, analysing the effect of different variables and testing the validity of alternative solutions, they were able to provide advice on the basis of which decisions of the greatest importance were taken. This scientific approach had considerable influence, for example, in greatly increasing the effectiveness of the numerically small RAF Fighter Command during the Battle of Britain, in reducing the menace of submarines and in improving the maintenance of aircraft. A novel and probably fundamental feature of operational research was the direct and close relationship of the scientific group with the senior officer responsible for reaching the decision. These techniques are now being adapted to the needs of peacetime economy.

During wars there is a great upsurge in the use of scientific capital; existing knowledge is heavily drawn upon, applied research is supported as a vital national necessity, speed of development from fundamental scientific concept to finished product is many times quicker than in peacetime. During the second world war, a high proportion of fundamental research scientists were diverted to military problems. This not only stimulated the defence research effort, but also had a valuable influence on the scientists concerned who, on later returning to their university laboratories, retained a practical interest in applied science.

In production methods, too, the concentration of effort and skill which is most commonly called forth by national instincts of preservation during wars gave rise to sweeping changes, enabling new processes to be introduced and equipment of the most complicated type to be manufactured rapidly. The very high efficiency and speed of production, for example, of tanks and aircraft, unthinkable at the outbreak of hostilities, was only made possible by radically improved methods of assembly and inspection, component standardization and elaborate systems of sub-contracting. Previously, technical advances in military equipment had only gradually influenced normal peacetime manufacture; in fact, a slackening period of reaction usually followed the hectic activity of war. This was not so after 1945; the increased tempo of technological development persisted.

EVOLVING METHODS OF MANUFACTURE

To the consumer, changes in the character and design of industrial products are more striking than the methods of industry themselves; yet the evolution of production methods has been as radical as that of materials and products. The initial mechanization of the industrial revolution was simply a speeding up, first by the application of water power and then by steam, of processes formerly performed by man or animal. As engineering developed and new materials and tools became available, it became possible to perform several processes by a single operation, or to undertake operations of a complexity or force far beyond the capacity of the human body. Nevertheless, mechanization remained until recently a projection, however much magnified, of the physical capacities of man.

The elaboration of multi-purpose tools has continued, but the complexities of engineering construction, with the need to move irregularly shaped pieces of metal from one position, fixed with great precision, to another position equally precise, have made it difficult to establish continuous methods of manufacture. The chemical industry lent itself more easily to improved methods. At first, chemical products were made in batches; later, as market demands called for larger quantities, and as chemical engineering techniques

were elaborated, continuous processes became common, mainly because of the ease with which fluids can be transferred from one vessel to another by pumping or by the force of gravity. Such continuous methods necessitate control and, in the case of liquids and gases, changes in the system are easy to record through properties such as temperature, pressure, flow rates or viscosity. The development of a more and more complex instrumentation, including self-recording electronic devices, has increasingly obviated the need for manual control and inspection. The highest elaboration of such methods today is to be seen in large oil refineries and in sections of the heavy chemical industry, where vast amounts of varied and complex products are to be seen issuing from complicated instrument-controlled plants which appear to be largely unattended.

In the engineering industries the trends are now also rapidly leading towards automatic production, especially in the manufacture of products such as automobiles, where a large, uniform and uninterrupted output can justify the initial huge outlay on jigs and fixtures, transfer machines and material-handling equipment. The next stage in the development of production methods, namely automation, is only now emerging. It involves completely new principles and will be briefly discussed later.

The increasing complexity of both products and methods has, of course, necessitated the design and purchase of extremely expensive manufacturing equipment, and has brought about a tendency for the newer sectors of industry to be organized into large firms with great capital resources. The rise in the capital required per industrial worker since the beginning of the century is a clear indicator of industrial change. It has also made necessary a more systematic approach to the efficient use of expensive machinery, and, consequently, to a scientific study of planning and of management.

Scientific management, starting with F. W. Taylor at the turn of the century, was, like the rise of science itself, the work of the inquiring engineer rather than of the scientist. But, here again, the trend is increasingly towards the use of scientific method. The earlier attempts at measurement and rationalization of work, for example, while attempting a quantitative description, depended essentially on subjective judgement. Moreover, they were introduced prematurely, without sufficient appreciation of social and psychological aspects, and often during a period of mass unemployment, so that they became identified in the minds of many operatives as just another tool of exploitation by employers, the stop-watch appearing as the symbol of an inhuman industrial system. Likewise, the simplest method of substantially increasing the efficiency of use of capital goods—the introduction of the shift system—while accepted for processes such as steel-making, where continuous work is inevitable for technological reasons, has met with much resistance, especially in the traditional sectors of industry. Mechanized assembly work, first introduced on a large scale in the 1920s, had obvious

economic advantages and has indeed resulted in cheaper production and an expansion of markets, thereby raising the standard of living of industrialized countries. Nevertheless, its introduction has also meant a loss of craft skill and that sense of frustration on the part of the individual worker which was so devastatingly depicted in Chaplin's 'Modern Times'.

By the time war broke out in 1939, it was clear that industrial change had reached a point where it was not only affecting the life and attitude of the individual worker, but was also having a major impact on the economic, social, political and cultural life of all industrialized countries. The war gave a new stimulus to these evolutionary processes, and the problem which faces us today is whether man is to be the victim of the machine age and of his own prosperity or whether he is to become its master.

THE PRESENT POSITION

The end of the war marked the beginning of a new era. Throughout the world there were signs of an awakening of social conscience and of a determination that the mistakes of the past should be rectified. One aspect of this feeling has been the enhanced importance of international contact and action in many fields of human activities. The United Nations and its Specialized Agencies thus came into being. There has also been a general recognition of the danger and instability inherent in the continued co-existence of the extremes of riches and poverty, both as between nations and as between citizens of the same nation. On the national level, this recognition has led to political change, a demand for higher standards of living and, especially in the more industrialized countries, to new policies of education and social welfare. On the international level, it has given rise to great schemes of technical assistance, such as the Marshall Plan, the United Nations scheme suggested by President Truman's Point IV speech, and the Colombo Plan.

Throughout the world there has been a powerful movement to raise economic levels. In the less developed areas strenuous efforts are being made to improve agriculture by scientific means and mechanization, and at the same time to raise the standard of public health and education. To take a single example, the discovery of DDT has, by controlling malaria, given possibilities of a richer, healthier life to millions of people in tropical areas; but, at the same time, it has aggravated population pressures. One obvious measure for underdeveloped areas is the creation of secondary industries in a hitherto exclusively agricultural economy. Factories for the manufacture of textile piece goods, agricultural fertilizers and relatively simple metal products have sprung up in an effort to avoid importing goods and to reduce the under-employment common in such areas.

In the highly industrialized countries there have been deliberate attempts, by fiscal and other means, to attenuate the disastrous cycles of boom and recession which marked the inter-war period. Policies of full employment have been accepted and maintained, and state economic planning has been in full operation in some countries, while in others there has been a partial nationalization of industry, especially of public utilities. Concepts of the functions of industry have changed; for example, a director of one of the biggest British corporations defines the role of industry as 'supplying the goods and services needed by the community with the minimum consumption of real resources'.

There are many types of industrial organization in operation in different parts of the world; in Eastern Europe, State capitalism is employed with comprehensive central planning of the national economy. In Yugoslavia, a type of syndicalism is in operation whereby individual industrial plants, competing vigorously against other enterprises within the country, are governed by an elected workers' council; profits are distributed on the basis of the annual balances to all workers, from unskilled hands to general manager, in proportion to their wages. In the U.S.A. and Western Europe, the pattern is one of private enterprise, in some cases accompanied by partial nationalization of industry. Government economic control is exerted only moderately, through fiscal measures, national investment and exchange policy, and labour legislation. In all these countries taxation remains very high.

There have also been radical changes in worker-management relations. Policies of paternalism, at one time so successful in enlightened firms, are no longer acceptable to the workers. There is a growing recognition that a healthy situation can exist only if there are strong and progressive trade unions and employers' organizations which can negotiate with one another. It is increasingly clear that higher productivity can only be achieved if workers and management understand each other's point of view and share common objectives.

It might be expected that the growing industrialization of countries which have hitherto been exclusively primary producers would menace the economy of those depending mainly on exports. In practice, however, the exporting countries as a whole have not suffered from this cause, although particular industries have been hit. Industry in developing countries has an immediate need of capital equipment, and, in any case, as industrialization proceeds, national income increases and trade grows. The net result is an increase in trade with the newly industrialized countries, though there is a radical change in the type of goods imported.

World industrial production has doubled since 1929. Since the war the volume of world trade has risen by 6-7 per cent per annum. The biggest contribution to the increase has come from trade between manufacturing countries, although trade between these and the primary producing countries

also continues to rise. This growth of industrial products without a proportionate increase of demand for primary goods is itself interesting and may be explained by the rise of agricultural productivity in the industrial countries themselves, the trend towards industries, such as engineering and electrical manufacture, which use a relatively small quantity of primary products, and the growing substitution of synthetic for natural products (synthetic detergents instead of soap, and man-made instead of natural fibres).

Even more significant than the change in the total volume of manufactured goods is the change in the type of these goods. This is clearly illustrated by Table 1 which compares the growth of employment in two of the new science-based industries with that in traditional industries in various countries.

TABLE 1. Employment in Selected Manufacturing Industries, 1953 (1937-38 = 100)[1]

Country	*All manufactures*	*Textiles*	*Chemical*	*Electrical engineering*
Argentina	168	182	233	471
Australia	162	142	204	—
Canada	201	139	248	362
France	115	92	129	—
Sweden	119	94	154	161
Switzerland	140	97	173	—
United Kingdom	111	73	199	163
U.S.A.	169	96	199	324

As can be seen, the newer industrial countries, such as Canada and the U.S.A., have increased their total industrial labour force much more than the older manufacturing countries of Western Europe, but even in the latter, employment in the chemical and electrical industries has increased strikingly, although that in textile manufacture has shrunk. Countries still at the beginning of industrialization, such as Argentina, Australia and Canada, show large increases in all industrial sectors, including textiles, but the phenomenal rise in some specific industries represents merely the jump from almost nothing to not very much.

The change in the industrial pattern brought about by science is most marked in countries already highly industrialized, especially those like Switzerland and the United Kingdom which live on exports. Such countries, which have to import not only raw materials for their industry, but also a high proportion of their food, are already being forced to modify their industry rapidly in the direction of manufacture of capital goods, complex

1. Report of the Director-General, ILO, 1955.

electrical equipment and chemical products which have a very high conten of workmanship, craft skill and research in relation to the value of importe raw materials. Human resources and skills are, in fact, the only major asse which such countries possess; and they must make the best possible use o them by concentrating on the application of research to industry. The expor trade of the United Kingdom is already reflecting this trend.

TABLE 2. U.K. Exports of Manufactures

	1913	*1928*	*1938*	*19*
Total ($ million)	1,990	2,758	1,732	6,08
Proportion of total contributed by:				
Machinery, transport equipment	16%	20%	32%	45%
Textiles miscellaneous manufactures	62%	61%	47%	30%
Metals, chemicals	22%	19%	21%	25%

The prosperity of the United Kingdom was built on cheap coal; it is probabl that such prosperity as it may enjoy in the future will spring from expensiv coal, for the increasing difficulty of mining coal is already forcing Britain t steer her scientific research efforts in new directions. The high price of coa is making her a pioneer in the development of nuclear energy. The new techniques, materials and equipment which are emerging as a result o this effort may, in turn, open up new and substantial export possibilities, al of which will bring about still further changes in the pattern of industry.

Apart from the broader aspects of overall industrial change, there ma be sweeping changes within individual industries and within individual firms. It is difficult to make an estimate of the rate of such changes, since ver few enterprises publish detailed information; furthermore, such evidence a is available comes from the larger industrial corporations which are usuall many years ahead of smaller units in the same industry in the same country. In spite of this, it is worth quoting some information supplied by American firms, which must reflect to some extent the experience of similar companie in Western Europe.

A large chemical corporation. In 1954, new products introduced on th market during the past 25 years accounted for half the company's produc sales.

A specialized chemical firm. During the past 10 years, this firm doubled it sales, and new products introduced during this period accounted for 25 pe cent of the increase.

Another large chemical corporation. During 1953, 40 per cent of its profit came from products not manufactured ten years earlier.

A large pharmaceutical house. During 1953, 78 new products were introduced.

A pioneer electrical corporation. Television, which did not exist commercially in the U.S.A. eight years ago, accounted for 50 per cent of its total volume of business over the past seven years.

A building materials and component producer. In 1953, about 47 per cent of sales represented products new or radically improved since 1940.

A large proprietary-brand food company. Products new since the war accounted for 24 per cent of the company's sales in 1953-54.

The rate of change appears to be high even outside the science-based industries, at least in some countries. In metallurgy, new metals such as titanium and zirconium are being developed, new high temperature alloys have appeared for use in gas turbines, and many types of special steel and light alloy have been provided in response to particular performance demands.

In the United States, the output of plastics has been doubling every few years, and novel types, such as silicones, polyethylene and polyesters have been recently in great demand. Production of man-made fibres other than rayon has also been doubling every few years since nylon came into mass production about 1940. Equally striking developments can be quoted from the aircraft industries, the electronic industry where transitors are making possible entirely new types of equipment, gas turbine manufacture, and the petro-chemical industries.

On technical grounds there is no foreseeable end to this growing application of science to industry; on the other hand, this trend may well be slowed down by reason of the mounting human problems which it creates. The increasing degree of specialization, for instance, and the number of such specializations which go to the development of a single product are already proving a difficulty to both entrepreneur and production manager, who must have sufficient knowledge of each speciality to assess what each can contribute in order to make the best use of the resources available.

The social implications of industrial change are indeed, as yet, only partly understood, although the importance of applied science and scientific leadership for the prestige, the well-being, and even the survival of a nation is now widely recognized in parliamentary and governmental circles. Moreover, science is now increasingly affecting foreign policy. For all these reasons, scientific development can no longer be considered in isolation; economic, social, political and psychological factors must interact henceforth with the technological ones, if the application of science is to be for the good of mankind. We appear to find it easier to invent new devices, whether they be guided missiles or television sets, than to learn how to use them wisely. Likewise, scientific industry has become so complex that its organization and its consequences challenge man's wisdom as well as his ingenuity. That

is why in this, the third phase of our industrial evolution, the social and management sciences must play an important role alongside technological development.

THE UNDERDEVELOPED COUNTRIES

Some 60 per cent of the human race is still supported by the primitive pursuits of hunting, fishing and subsistence farming. Even in Europe vast numbers of peasants and smallholders still use methods which have remained unchanged for centuries. Yet there is now almost everywhere some connexion, however superficial, between the most primitive and the technically most advanced. The Australian aborigine still living a nomadic, neolithic life sees the great modern aircraft flying between Sydney and Darwin; African tribesmen are drawn to the new mining centres of Tanganyika and Uganda, and from far Nyasaland to the gold mines of the Union of South Africa. Wages earned in the Rand are altering tribal life many hundreds of miles to the north, replacing subsistence economy by money economy.

The evolution of man from a nomadic to a technological existence has taken several thousand years; yet today, in many places, individuals accomplish this transition in a few years, generally in response to the demand for raw materials of the industrialized countries. The sinking of oil wells in the deserts of the Middle East and the construction and maintenance of pipelines require labour which can only be recruited from the nomadic herdsmen of the region. The herdsmen forsake their tents, live in houses and villages, become familiar with the amenities and frustrations of urban life, and learn technical processes. Beliefs and customs accepted for centuries may be abandoned in the process, tribal systems destroyed and authority undermined to give place to a somewhat colourless existence without faith or objective beyond immediate economic gain. And it is not only the needs of the industrial countries which are causing such changes, for there is also an urge, everywhere, to raise the standard of living of the underdeveloped areas.

As has already been said, the present development of these areas generally proceeds by two main means—improvement of agriculture and introduction of a measure of industrialization. This usually goes hand in hand with new medical and public health systems, especially in tropical areas, an improvement in general educational standards and the provision of vocational training.

The agricultural improvement is generally accomplished by better breeding methods for plants and animals, draining and irrigation, use of fertilizers and better methods of husbandry, in addition to mechanization. It results, as a rule, in high yields per worker, and consequently, makes still more labour

available for other activities. Disparity in agricultural productivity between countries is great, and it is significant that the nations most advanced in industry and technology are those which tend to improve their agriculture the most. Advances in agriculture also create employment in the tertiary sector of the economy (transport, commerce and other services).

Industrialization in underdeveloped areas frequently results in the introduction of quite advanced technologies, because it is natural to use the most efficient machinery and methods evolved elsewhere when building, say, a textile mill or a sulphuric acid and fertilizer plant in a 'new' country. Such countries as India or Brazil may, in fact, be able to avoid the painful industrial growth of the last 150 years in England, just as the nomadic Arab, in becoming an oil worker, has jumped, if not always painlessly, 2,000 years of social evolution.

However, the change from a subsistence agricultural to a dynamic money economy necessitates personal and social readjustments of such a character as to challenge the adaptability of man. The introduction of more efficient methods in agriculture or industry seems to the worker living in an environment of under-employment merely to aggravate the difficulties of day-to-day existence. The fact that, in the long run, technological improvements lead to greater prosperity for all and eventually create new jobs and opportunities, is not a persuasive argument to those whose livelihood is about to be abolished by mechanization. In any case, the new job, when it eventually materializes, may necessitate a complete change in the place and in the whole way of living of the family, so that an instinctive fear of change is aroused. The reality of such problems is well understood by the governments of many countries, such as India, now engaged in rapid development. Much hardship can be avoided by careful preparation, especially by joint labour-management activity, and by encouraging, as an interim measure, methods of production such as village handicraft schemes which employ much labour. But here again, all such planning must integrate technical, economic and social considerations.

THE EXPANDING ROLE OF THE SCIENTIST

The overwhelming changes wrought by science have naturally had their effects on the scientist himself. The worker in fundamental research, intent only on extending the frontiers of knowledge, has always needed a patron's support. In the early days the patron was frequently a prince or an aristocrat. At the beginning of the industrial revolution it was the enterprising industrialist who to some extent took on this role; but as the nineteenth century progressed, scientific research became a profession, and the industrial and mercantile rich endowed scientific chairs at the universities, or left their

fortunes to create great foundations for the support of research. High taxation is gradually putting an end to this kind of patronage, and today the main support of research comes from the big industrial corporations and, above all, from the State. In most countries, universities are forced to seek an increasing proportion of their finances from the national (or local) treasury. Fortunately, this change has taken place so slowly that acceptance of government support has not been at the expense of the universities' independence. In the early days of government financing, the sums were too small to warrant interference, and now that they are very large, the importance of science to national well-being is so obvious that most governments are wise enough to accept the position as it is.

The natural scientist is also finding his place in industry. For a period, academic snobbery deterred the best research brains of Europe from going into industry, in contrast to the position in the U.S.A. where applied research was socially very respectable. In general, chemists, metallurgists and, later, biologists and physicists were to be found mainly in rather subordinate positions—technical analysis and control, or product development. This was the phase of 'the scientist on tap, but not on top'. In Europe, particularly, he did not easily find his place on the boards of companies or in top management.

However, as the pattern of industry changes, and technical considerations enter more and more into the production and investment policy of enterprises, it is becoming accepted that at least a proportion of those who make policy decisions should have received training in scientific or engineering subjects. This has occurred in many of the larger firms, especially in the newer industries where chemists and engineers easily find their place on company boards. The stage is being reached where techniques of great variety and significance are available for application, and these demand from management at least a general understanding of the possibilities they offer, as well as an ability to formulate needs in terms which will have meaning for the scientists who have to meet them. This is particularly true in electronics, where principles, circuits and control mechanisms of all kinds are available for use in industry—if the electronic scientist is close enough to management to understand the specific needs of his firm. The situation is analogous to that which obtained during the war: new arms and devices were developed quickly and brilliantly when a real understanding was reached between the service chiefs, who knew what weapons and equipment were required, and the 'backroom boys', who knew what to do when they were told what was wanted. Indeed, the scientists frequently suggested possibilities based on new scientific discoveries which could not have been known to those formulating demands. It is, in fact, one of the fundamental requirements of the science-based industries of today that formulation of needs and presentation of scientific possibilities should be closely related to one another. But, in

industry as a whole, there is still a considerable gap between science and management.

If this gap is to be speedily bridged, training in both science and management will have to be modified. The present type of undergraduate academic course in science and engineering, followed perhaps by two years of research working for a Ph.D, is undoubtedly suitable for the training of research workers in both fundamental and applied science; it may also be appropriate for those who will find their place in production control and other essentially technical activities in industry. But it may be questioned whether university research at the post-graduate level might not with advantage be replaced, at least in some cases, by advanced courses of specialized technology. Equally important is the need to include a greater proportion of science in the general education of those who will be the managers of the future.

The growing need for science in industry at all levels, from the boardroom to the shop floor, has already, in the more industrialized countries, created a demand for scientists which is hard to fill. An increased intake of students in the science faculties of universities, which would be a solution, is hampered by the present shortage of science teachers in schools. It is also felt that industry may attract too many of the best research brains at the expense of fundamental work, especially if it offers great financial rewards. There are relatively few creative research leaders in any country capable of making the significant discoveries on which advance depends and of leading schools of research. The greater number of these may prefer to remain in academic life, though there is scope for some of them in the research laboratories of outstanding firms. Social, economic and cultural conditions in each country will determine what proportion of this scarcest and most valuable category of manpower shall devote itself to adding to the reservoir of the world's knowledge, and what proportion shall spearhead its application. The top managers of the science-based industries of the future, who will increasingly be people of scientific training, will not as a rule be of the same temperament or type of mind as the research leaders. They may well prove to be equally scarce, but will come from a different stable.

GOVERNMENT AND SCIENCE

The fact that the State now finances a large proportion of scientific work in the national interest has aroused fears that government need for research may threaten the free development of new ideas. In most countries, however, an understanding has gradually emerged as to which categories of scientific work are appropriate for government support, and which should be left to industrial and other enterprise. In general terms, the government role appears to lie in the following fields, although differing conditions and levels of development account for variations in particular countries:

1. To provide the necessary manpower trained in science and technology through general, university and vocational education.
2. To make possible the development of research leaders, and to contribute to the general increase of knowledge on which future well-being depends, by the encouragement of fundamental research in universities; this is done by supporting promising post-graduate students for a period of free-choice research, rather than by sponsoring 'project research' on behalf of government agencies.
3. To provide the very expensive research equipment necessary for advance in fields such as nuclear physics or radio-astronomy.
4. The support of medical research.
5. Research for the armed forces, which is proving a heavy drain on scarce research workers in many countries because of the variety and complexity of new equipment.
6. Research on the location, conservation and use of natural resources, such as minerals, water supplies and forests.
7. Research in support of public utilities (road research, water pollution, fire prevention, the protection of food from pests, etc.).
8. General background research and testing for industry as a whole, including maintenance of standards.
9. Research for industries where the units are too small to undertake or even to apply its results without assistance (agriculture and building).
10. Encouragement by financial and other means of co-operative research for particular industries.

It is generally considered that the great bulk of research for industry should be done by the firms themselves, and governments frequently encourage this by fiscal means and through investment policies. It is recognized that co-operative research is complementary to, but no substitute for, research by the individual enterprise, whether private or nationalized. The speeding up of technological improvement, especially in the smaller firms, is being studied seriously in many countries, but no generally effective means have yet emerged.

In most countries there are one or more governmental or semi-governmental organizations possessing some or all of the above functions. In the U.S.S.R. and some other countries, the National Research Council is a strictly governmental body controlling a number of institutes for particular subjets; in other countries, it is considered that the national organization should be an independent body receiving government subvention.

Another indication of the penetration of science into government is the appointment by some states of scientific attachés to their embassies abroad.

THE PRODUCTIVITY CONCEPT

In the strict sense, productivity is an efficiency factor, the output of a system in terms of any particular input factor. Thus it might be expressed in terms of the output of a factory or of a whole industry per man hour or man year (labour productivity); or in terms of output per ton of coal used, per acre of land or per unit of capital employed. Too often the term productivity is used as identical with labour productivity. But productivity, especially in Europe, has come to denote more than an input-output ratio; it represents a new attitude to industry, an inquiring approach intent on describing or measuring a system at work, with a view to suggesting how to obtain an improved yield for the common good.

Another aspect of the productivity movement which has an outstanding importance for industrial and social development is that it necessitates the co-operation of management and labour towards a common objective, namely the improvement of living standards generally. Such co-operation can only be real and effective if it is based on an equitable distribution of the fruits of higher productivity through the normal machinery of collective bargaining.

The productivity movement, which is growing in strength in many countries, is one of the obvious facets of the third phase of industrial evolution, where social and psychological factors interact with technological development. It is already producing significant modifications in the thought and practice of both labour and employer organizations.

The measurement of productivity is considered by many governments important for planning and policy making, since knowledge of rates of productivity change is useful in determining how quickly an economy may be allowed to expand without risking inflation; it is important, too, in connexion with terms of trade and balance of payments problems, and with respect to wage and price levels.

Productivity may be measured at all levels, the 'plant' level as well as the 'national' level. Comparisons of productivity are of the greatest importance; indeed, the studies of Dr. L. Rostas on the productivity of various industries in the United Kingdom and the U.S.A., by drawing attention to the inferior position of British industry, made governments, employers and trade unionists aware of the situation, and helped to create the present European productivity movement. International comparisons can, however, be misleading; only if productivity is measured in comparable terms is it possible for a single industry or a particular country to draw on the experience of others. Much research and development of method is required before such comparisons can be generally useful. International productivity comparisons must likewise be used with caution owing to the differing pattern of organization from country to country.

Productivity measurement can also be of great value in the narrower context of individual plants, especially where these employ similar production methods. Such measurements, either for the plant as a whole or for particular departments or processes, offer a useful method of analysing efficiency and of recognizing trends. This is done to some extent by every well-run firm, but here again systematic development of method is required if reliable data are to be obtained. Plant-by-plant comparisons have proved strikingly useful for industries such as textiles, garment making, shoes and ceramics, and for engineering assembly, but much less so for non-repetitive manufactures. Such comparisons frequently indicate a productivity difference as great as four to one between the most and the least efficient producers in an industry. Furthermore, methods such as those developed by the Shirley Institute in Britain may elucidate the reasons for those differences and suggest how productivity may be increased without major capital expense, by means such as changes in the deployment of labour or alterations in plant lay-out and usage. This type of study has also on occasion provided the basis for a rational wage system.

Such comparisons, when they are not derived merely from the firm's books but take into account actual manufacturing processes and organization, approach closely the methods of operational research, i.e. the application of scientific method to a system in operation. The techniques employed vary a great deal. Use is frequently made of deductive statistics, although in complex cases the first stage may be merely an accurate qualitative description of the system and of the operating variables. Usually, however, the methods of operational research are quantitative. During the war, operational research depended for its success on the direct and intimate relationship between the research unit providing the analysed data, and the senior officer responsible for making the decision. In industry, this relationship is usually not so clearly defined, nor are the tasks of operational research groups quite so comprehensive. Nevertheless, the method is important and could well be exploited more. The techniques are very varied and frequently have more promise than plant-level productivity studies, especially for the investigation of non-repetitive manufacture. The two methods are, of course, complementary, and in woollen manufacture, for example, it has been found useful to employ both.

Another aspect of the use of quantitative methods in industry is personified by the industrial or methods engineer. Although the techniques of Taylor and his successors were somewhat crude, they contributed greatly to manufacturing efficiency by their concentration on real operations and on the need for measurements. Such methods have been used extensively for the improvement of technological processes, and still more in relation to rate fixing and the establishment of bonus incentive schemes. Since the war a new impetus has been given to the use of these methods, partly by the develop-

ment of industrial engineering techniques themselves, but still more by the recognition of their human and social implications. In Western Europe, and especially in the United Kingdom, where work-study campaigns have had considerable effect, these methods have proved useful where confidence could be established between employers and operatives.

To return to productivity, the substantial differences between the United States and the Western European countries led to a consideration of why these differences existed. It soon became evident that there was no simple explanation, and that productivity is determined by a large number of intangible and interrelated factors. These may be economic, fiscal, technological, social or psychological in character, and in many instances it is impossible to say whether a particular feature is a cause of high productivity or merely a result of it. For example, productivity generally goes hand in hand with high wages; therefore the raising of wages may be said to lead to high productivity; but it may also be argued that it is the raising of productivity which leads to high wages.

Even the degree of mechanization in terms, say, of horse-power per worker, is not always a reliable indicator of productivity. For, though international comparisons show a close positive correlation between horse-power and output per operative, this relation only applies to manufacturing industry taken as a whole; studies of a similar kind for individual industries reveal a much more complex picture. Indeed, the more data available on productivity, the more complex appears to be the nature of its determinants.

The most useful attack on this problem appears to lie in the selection of a single major determinant of productivity, and analysis of how it is affected by other factors. It would seem that the greatest single factor over a period of, say, ten or twenty years is the rate at which new scientific and technical ideas are introduced into industry. In a particular case, productivity may rise steadily at a rate of 2-3 per cent per annum over a decade. Then a major change of process with a high degree of mechanization may be introduced, and, as a consequence, labour productivity may jump 200 per cent in a single year. Technological innovation is not, of course, merely a matter of creating new knowledge by research; it depends greatly on how such knowledge is applied, on general economic factors, national taxation policy, and on the intangible qualities of leadership and good management. The productivity movement in Europe, realizing the importance of all these factors, regards technological innovation as a central problem to be attacked at many points—by the development of new techniques, by training methods and by a study of resistances to change.

TECHNOLOGICAL INNOVATION

Technological change may be considered as the consequence of a chain of events, all of which are important in determining its rate, and consequently, that of productivity increase and the rise in living standards. The main links in the chain are: pure research, applied research, communication of scientific knowledge and ideas, technological development, managerial initiative and skill, and worker acceptance. This sequence is so important with regard to the impact of science on industry that the various links will be discussed separately.

Pure Research

After centuries of slow material advance, which depended on invention and ingenuity, the systematic, analytical approach has come into general use only in the last few decades. It is now generally accepted that pure research should be left completely free, that exceptional creative minds able to probe into the unknown and make the relatively few significant discoveries on which progress depends should be allowed to choose their own research topics as their genius dictates. The university seems to be the best location for pure research; not only does it provide a suitable intellectual environment, but there also seems to be considerable advantage in combining research with the teaching of advanced subjects. Furthermore, the flow of selected students who, though not intellectually mature, are at the age when intuitive creative faculties are at their height, seems to have a perpetually revivifying effect on the work and ideas of established research leaders. It is difficult to create equally propitious conditions for research outside the campus. In some of the Eastern European countries there has been a tendency to separate research from teaching and to create research institutes as branches of the academy of sciences. This may have been due to the great increase in the number of undergraduates since the war, which by creating a heavy load on teaching, crowded out research. It has not yet been proved, however, that the research institute separated from the university can maintain its vigour undiminished over a period of years.

As the prospects of a scientific career become more attractive and the university research students increase in numbers, there is a natural tendency on the part of government departments, the armed services and industrial firms to encourage the universities to undertake research on their behalf. Financial help received in this way for project research is naturally welcome to universities suffering from insufficient financial support. As a consequence, since the war there has been a tendency, especially in the U.S.A., for university research schools to devote a considerable proportion of their effort to specific projects commissioned by outside bodies. Such research is generally

of a type known as 'objective fundamental', that is aiming at uncovering new knowledge required for particular applications demanded by industry or government. It is thus compatible with the normal work of a university research school and, if accepted in moderation, can be useful in strengthening the research school, in extending knowledge, and in facilitating new technology. However, the financial temptations of project research are great, and there is a real danger that it may grow to such an extent as to jeopardize the free choice of research subjects. Governments would do well to consider whether their long-term needs would not be better served by themselves providing more adequate financing for university research.

Applied Research

While the revolutionary ideas orginate mainly from pure research, a great deal of investigation is required before they can be applied. Indeed, highly industrialized countries require a larger proportion of their scientific effort to be devoted to applied than to pure research.

Applied research for industry is primarily the responsibility of the individual firm; yet the industrial scene is so complicated that, as will be seen, many types of research organizations have come into being.

In the newer industries which have been created on the basis of scientific discovery, it is recognized, especially by the larger firms, that they cannot afford to dispense with research, which becomes, indeed, a normal part of the investment programme. It is fully realized that only a small proportion of the research undertaken will lead eventually to commercial exploitation, but that a sufficiently large amount done with skill may be expected to yield some profitable applications. In the traditional industries, however, and amongst the smaller firms in all industries, the possibilities of research are not sufficiently appreciated. Too often, it is regarded as an inevitable but unwelcome overhead, and is carried out without conviction, with insufficient planning, and with impossible demands for quick results. It is ignored altogether by many of the firms which are most in need of it.

The progressive firm with an intelligent research programme must determine its optimum level of research, bearing in mind that a successful research outcome may mean considerable outlay in new plant and machinery. The development costs of a project may amount to about ten times its research costs. Of course, only a fraction of applied research is carried through successfully to production. Nevertheless, it is obvious that the research programme of a firm must bear some relation to its capital investment possibilities. One large American corporation finds that, for every dollar spent on research, six dollars have eventually to be invested in new plant and equipment as a result.

The ratio of research expenditure to sales is a useful indication of

research activity. It is high in industries such as chemicals and electronics which are inherently research-based, and here leading European firms have approximately the same research policy as their American counterparts. The highest figures are to be found in such sectors as drugs and fine chemicals, where there is great diversity of product and a high rate of scientific advance; for some American firms, the ratio may be between 4.4 to 8.5 per cent. In other branches, such as oil, glass or steel, high bulk sales of a smaller number of products tend to reduce the research/sales ratio, though the basic scientific activity may still be very great. Detailed surveys of this kind are at present being undertaken in the U.S.A. and Britain.

In addition, to the research laboratories of firms, there are also sponsored research institutes which have been very successful in the United States and are now establishing themselves in Europe. They offer first-class research and development facilities to firms, trade associations or governments lacking sufficient facilities themselves or wishing, for some reason, to have research undertaken independently. The client paying for the research normally has full ownership rights of the results. Curiously enough, these sponsored research institutes are used, in practice, much more by medium and large firms and by government agencies than by the smaller firms which have no research facilities of their own. The profits of these institutes may be distributed to stockholders or ploughed back.

Still another type of organization is the co-operative research association designed to undertake common research for member firms in a particular industry. This system has been most thoroughly developed in the United Kingdom, where there are some 45 such research associations. Each undertakes general background research for an industry as a whole, while the member firms may do additional research according to their individual needs. Far from replacing scientific initiative within the firm, the research association movement has, on the contrary, stimulated its members to start small laboratories of their own, so as to make use of the general technical advances resulting from the association's work.

The experience of the Netherlands shows that sponsored research can be compatible with co-operative research within a single institute.

There are some research problems, particularly costly ones, which can best be undertaken on an international basis, with great saving of material or human resources. A new movement in this direction is growing in Europe with the international flame radiation group and various other projects initiated by the European Productivity Agency of OEEC on subjects such as the low shaft (oxygen-fed) blast furnace, photogrammetry, de-salting of water, and prevention of the fouling of ships. Wherever possible, such projects are centred in existing European scientific institutions most appropriate for the purpose, i.e. they are based on growth around existing experience and skill rather than on new organizations.

Development

The increasing complexity both of science and industry makes it ever more costly and difficult to translate the results of fundamental discovery into industrial production; yet economic and social needs demand more than ever before that the development process be speeded up. Indeed, the shortening of the period between discovery and production is one of the most striking features of our age. What formerly took decades or even centuries is now rushed through within a few years; the mass production of jet aircraft, the establishment of the synthetic rubber industry and, still more spectacular, the evolution of nuclear energy from a new theoretical concept are cases in point.

Now the rapid and competent construction of a chemical pilot plant or of engineering prototypes calls for new types of technologists. In the United States, and more recently in Russia, great changes in training facilities have been made to ensure that there will be a sufficient number of highly qualified technologists, such as chemical, electronic, and production engineers. Indeed, the leading position of American industry may be due to the recognition of the need for quick development and to the training of engineers for that purpose. Leaders of American industry claim that much of their production is derived from a quick recognition of the practical significance of basic scientific discoveries made elsewhere, especially in Europe, followed by rapid and particularly competent development work. On the other hand, European countries, in spite of possessing leading research schools, are often so slow in developing their own discoveries that they become uncompetitive. Although this is due mainly to the general conditions in which the decision to innovate is made, there is no doubt that insufficient attention has been given in Europe to the techniques of modern technological development and to the training of suitable experts. However, it is no longer possible to ignore the magnitude of this problem, and all industrially advanced countries will in the near future have to train a high proportion of their scientific and engineering manpower for design and development work, for which there is already a great demand in many countries.

Communication of Scientific Knowledge

With the increase of research activity throughout the world, communication of its results becomes an ever greater problem. There are two separate needs: first, to ensure that each new research paper is available to scientists throughout the world; second, to bring results, particularly of applied research, to the attention of those who might put them to productive effect.

On the whole, the former task is adequately performed by the existing scientific journals of learned societies throughout the world. There are, how-

ever, two mounting problems in the dissemination of the results of pur research, one arising from specialization and the other from increasing cost

Ever-narrowing specialization in the natural sciences has the effect o narrowing the interest of the research worker within a certain field, sa chemistry, to a smaller and smaller proportion of the papers published i the journals in his field. The conventional method of publication is thu becoming very wasteful and, as the bulk of papers increases still further some solution will have to be found. Something like the proposal put forwar by Professor Bernal a few years ago, and received with indignation, wi probably have to be adopted in the end. The proposal was to publish paper only as 'separates' and to distribute them through an international clearing house so that each research worker would receive not a whole journal bu only separate papers on his particular specialization from all parts of th world. Such a scheme could be built around the existing publishing societie and without a central bureaucracy. As for the problem of cost, the creatio of any rational system of dissemination would require financial help fo publication from governments and industry as an intrinsic part of thei research expenditure.

Communication of research results to industry presents greater problems The larger, progressive firms, possessing good scientific information services are well able to scan the world's literature for discoveries they might apply but smaller firms, even when aware of the possibilities, lack the resources to survey the innumerable scientific papers which might be relevant. Ther there are the scientifically illiterate firms—in large numbers even in the mos industrialized countries—quite unaware of the world's growing fund o unexploited ideas. Many methods have been tried to bring new science t reluctant firms, but these methods are always used to best advantage b the more advanced firms which need them least. Thus, for example, th technical press is incompletely made use of in most countries, and wil remain so until the managements of small firms acquire some technical knowledge. Again, associations for co-operative research usually run well-organized information services: the research associations in the United Kingdom, for example, together with the Department of Scientific and Industrial Research, answer in all some 200,000 scientific and technological inquiries every year; but these come mainly from the more advanced firms. One useful approach is the appointment of field liaison officers who visit the firms of a region, identify problems, attempt to obtain some solution through a central information service and assist the firm in putting the information to use. Such a service is run successfully in Canada, while some of the British research associations maintain liaison officers whose services are restricted to member firms in the particular industry. But a full coverage of industry in that way would necessitate a liaison force too great for present resources.

Recent surveys of how new ideas reach industry indicate that in only a

small proportion of firms is there any person with responsibility for looking for new ideas of potential commercial interest. This may appear to be in contradiction to the picture of rapid evolutionary change already painted, but it must be remembered that, even in the most advanced industrial countries, it is, in the main, the large corporations which change the pattern of industry; the mass of small firms lags many years behind, although they still supply a large proportion of the total output. The need to improve productivity is focusing attention in many countries on the technological backwardness of small firms. One way of improvement would be by means of sub-contracts from larger and more progressive firms, but the problem cannot be solved until increasing scientific education provides a generation of managers capable of appreciating technical points and possibilities.

In the meantime, some advance could be made if particular scientific or technical improvements were written up in a form suitable for the average unscientific small-firm manager. An experiment along these lines is being undertaken by the European Productivity Agency, which is publishing digests from the technical press of several countries. These are not abstracts for scientists, but clearly written summaries, free from technical jargon, giving a simple presentation of an idea with some indication of its economic significance.

Managerial Initiative and Skill

This is the most critical link in the chain leading to innovation, because it is the manager who must make the decision to innovate. No matter how much research is done, if management is not interested in applying it—through lack of incentive, high taxation, indolence or simply fear of change—it can serve no useful purpose. Little is know as to how and why the decision to innovate is taken, although much has been written about it. In a given set of circumstances, one man will take the decision and another will not.

For example, change will be difficult to achieve in a family business which has been successful for several generations and where the major consideration of cultivating a modest family fortune will favour traditional practice and bar the outsider with ideas. Vastly different is the situation of the entrepreneur who stakes his own future and that of his friends on the development of an invention. Again, there is the professional manager who is not the owner and who will accept advice from many sources. Then, again, there is the case of the executive director in a huge nationalized corporation with its carefully judged investment programme, its stress on national interest and its relatively small incentive for the individual. Furthermore, national psychology may influence the decision. In the United States, for example, novelty is appreciated for its own sake, and it is often regarded as axiomatic

that there is great commercial advantage in being first in the field with a new product. In Europe, on the other hand, it is tradition which is valued for its own sake, and there are many businessmen who believe that the firm to introduce a major innovation bears an undue burden in the way of development costs and teething troubles not shared by competitors who enter later, when a new market has been created. There may be a rational basis for such attitudes, but we really do not know.

However, as industry becomes more complicated, there is a tendency for decisions to be taken less by the individual, and more by the group. For this, as for other reasons, it is necessary that the boards of companies should include a proportion of scientists aware of the potentialities of new basic discoveries. These men need not be recruited directly from the research laboratories; they may be promoted to the board from development, production or even the technical sales department, as long as they have a good background in science or engineering. Scientists are not specially endowed with those gifts which make the natural manager; indeed, the kind of specialization to which they are subjected at an early age tends to preclude that breadth of outlook which makes for industrial leadership. When, however, the good manager is also a person of scientific background, he tends, from his knowledge of changing systems, dynamic equilibria or the analysis of variables, to be of a type predisposed to consider change as a practical possibility.

Once the decision to innovate has been taken, management still has much to do. Experts, techniques and new principles may be available, but they must be brought together to practical effect by a formulation of the practical needs of the firm by management. The manager must first carry with him the middle management, and ultimately the operatives and their trade unions. He has to consider ways of providing capital, to start production planning and lay-out, establish methods, purchase equipment and prepare his marketing. In fact, modern technology demands from management an omniscience which can only be partly achieved by specialization of executive functions.

Worker Acceptance

Resistance to change is an inherent characteristic of a large section of the human race, and can become a formidable obstacle in certain circumstances. However, with the growth of powerful—and, on the whole, enlightened—trade unionism, it is unlikely that we shall ever see a return to the machine breaking tactics of the early phase of the industrial revolution. Nevertheless, major technical developments such as automation must be prepared for and explained well in advance of their introduction; otherwise resistance can build up dangerously.

The first necessity is information and explanation of what is proposed

and why; an unknown change is much more feared than one which is thoroughly discussed and understood. It is, in fact, just as important to appeal to the self-interest of the workers as to that of management, to dispel fears of economic loss or unemployment. The workers may also fear that adjustment to the new process may bring about a change of status as yet undetermined, or may involve a difficult re-training which the older ones may fear to be beyond their capacity. Even when the new process may have no direct effect on them as workpeople, it is important to secure their co-operation by convincing them that it is in their interest as consumers.

Much can be done to prepare for technical changes, particularly by slowing down recruitment for some months in advance and by establishing re-training programmes. But, above all, the manager must create an identity of interest between management and workers. This can only be done if the general conditions of work, remuneration and management are such that the workers can be sure of fair treatment and reward. When such conditions exist, they can produce in the operatives a sense of participation and a real pride in enterprise and achievement.

THE HUMAN FACTOR

One of the most characteristic features of the industrial scene of today is the growing importance of the human factor. Many employers have been giving attention to new methods of selection and transfer within the plant, so as to place workers in those jobs which they can perform most efficiently and from which they can derive most satisfaction. In some countries, full employment has made for the adaptation of work to suit older workers, or the physically disabled, or married women. Special thought has been given to problems of supervision and foremanship and to the training of management at all levels. The trade unions are also seeking to widen opportunities for upgrading and to educate their members in the problems raised by the new industrial evolution.

This recognition of the growing importance of the human factor in industry has been accompanied by a growth of the social sciences and an increasing interest in their possible application to the realities of the industrial society. There is still a certain amount of scepticism concerning research on human factors; yet the need to secure better industrial relations and the active participation of the operatives in technical development makes it unwise to neglect the growing possibilities of this kind of investigation. The social sciences can help industry in a variety of ways, e.g. in selection and training, the organization of processes, adjustment of physical working conditions, improvement of methods, and in the relation between individuals and between groups of people.

In the field of human relations, the contribution is at present potential rather than actual; but much has been gained in the last few years by subjecting these problems to debate, thus ensuring a wide exchange of views and experiences. In the United States, and more recently in Western Europe, much field research has been done in industry, mainly on uncovering the real nature of human situations and especially that of friction. It is most important that research of this nature be undertaken by groups of investigators from universities or other institutions whose impartiality would not be in question, since there is a real fear amongst workers and their unions that human relations research aims merely at discovering social and psychological techniques whereby employers can exploit workers. The European productivity movement has initiated human relations projects, undertaken either by individual countries or on an international basis, which seek to obtain the full collaboration of employers and trade unions in the establishment of research programmes, their execution and the discussion of their results. By human relations research is understood investigation of an industrial situation as it exists—the relation between individuals or groups, whether within the labour force, between labour and management, or within the hierarchy of management. Indeed, human relations problems within management, as for instance between line management and the functional expert, are of great practical significance today. There have already been cases where the study of a strike by independent social science investigators has uncovered the real reason for dissatisfaction of which strikers, unions and employers had been unaware, because concentrating on grievances which had no more than precipitated the stoppage. The results of such investigations should be equally available to all parties concerned, and they contribute to, rather than detract from, the process of collective bargaining.

PROSPECTS

It is really only in the last few decades that scientific discovery has exerted a dominant influence in changing the pattern of industry and of human institutions. There is every sign that this trend will continue and be intensified, not only through major discoveries which will lead to new products and new industries, but by a multitude of small innovations and by the gradual adoption of scientific method in production, management practice, planning, and in the study of social situations.

Among the revolutionary advances, the problem of photosynthesis, for instance, might be solved and, as a result, world food, population and political problems would change in character overnight; or an economic method might be found to utilize solar energy. But even without such major discoveries, the present reservoir of basic knowledge, if applied to practical

problems and fully exploited to meet men's needs, could so change the world's industry that it would scarcely be recognizable. In particular, the underdeveloped areas could make rapid progress, and industrial development in the advanced countries could provide goods in greater quantity, much more cheaply and with less human labour than today.

In fact, it is not science and technology that are lagging behind; on the contrary, they are putting at our disposal discoveries and techniques at a faster rate than our social wisdom can fully utilize. The challenge is not to the scientist, but to man as a social and political animal. This is the outstanding feature of the present, and third, phase of the Industrial Revolution.

The two developments with the greatest probable influence on human and industrial patterns are atomic energy and automation. Atomic energy has had vast military and political repercussions; one effect will probably be a reduction in the size of armies, and a consequent increase in the industrial labour force. But it has also had a great effect on industry in general. The need for remote control and manipulation, for instance, and for the detection of stray radiation, has already had a profound influence on industrial instrumentation and on chemical engineering; the techniques developed to produce uranium metal from low grade ores have opened up new possibilities in the use of minerals; novel methods of preparing pure substances in bulk have a significance apart from nuclear power. Still more important, nuclear energy has become a real economic possibility, and with it the cheap production of isotopes and new irradiation techniques will find valuable uses in industry and medicine.

The development of nuclear power generators is being dictated to a large extent by the economics of power production. In countries like the U.S.A. and Canada, for example, conventional sources of energy are still cheap and plentiful; consequently emphasis is mainly on research and development in the design of reactors. On the other hand, in countries such as Britain, where the fuel position is already critical, the emphasis is on the building of nuclear power stations to produce a substantial quantity of power as soon as possible, while at the same time investigating the possibility of more efficient reactors. The British programme at present envisages the construction of twelve nuclear power stations to produce a generative capacity of 1,500-2,000 megawatts at about the same cost as electricity generated by conventional means.

Another important possibility is the building of reactors in under-developed areas lacking in conventional fuels but capable of creating new industries if provided with cheap power. The smelting of minerals in areas remote from power resources is a case in point. Over a long period, nuclear energy will thus tend to concentrate industries near sources of raw materials rather than, as at present, near communication centres or power sources.

Automation is an advanced stage of mechanization in which complex opera-

tions are conducted in their entirety without human control. In practice automation becomes possible where at least three streams of technological development meet: the elaboration of multi-purpose machine tools and their linkage through transfer machines, the perfection of instrumentation techniques, and the development of electronic computors which can plan and control a system as a whole. Most automatic lines include feed-back systems where variation in the dimension or form of the product will adjust working conditions to produce the desired result. It is unlikely that automation will be introduced at a revolutionary rate; it is more likely that its introduction will be gradual. It will raise many problems. First, much study will have to be given to the economics of such processes since, owing to high capital costs, innovation must be considered carefully. Then, management at all levels must be willing to accept and operate the new methods and to alter conventional attitudes. Finally, operatives will have to accept radical changes in the nature of their work. As automation, and indeed the scientific complexity of industry in general, increases, there will be rising demands for more and more highly skilled workers and for all grades of management. There will also be an increase in the proportion of manpower required by the engineering and electronic industries.

Automation will, in fact, tend both to upgrade and downgrade work, providing highly specialized jobs, especially in design, construction and maintenance, and also routine but not unpleasant work in the subsidiary services. There will also be a continuation of the present tendency towards the growth of large firms owing to the high capital requirements of automatic plant, although there will always be a place for small, efficient, specialized units. The automatic factory is unikely to become common within the next decade, but the increasing extent of automatic working will be sufficient to produce considerable industrial strain and to necessitate the tackling of many difficult social and managerial problems.

Not the least of these will be the problem of human resources, particularly in the highly developed countries. The growing complexity and automation of industry will make necessary the training in science, engineering, design and management of as large a proportion of the population as possible. In fact, the proportion of the population capable of acquiring such skills will, to a large extent, determine the limits of expansion. As the standards of living —and of education—are raised throughout the world, countries with the largest populations, such as China, Russia and India, may assume a much larger share in the world's research effort. Those countries of the West which today lead in scientific research will thus become less important, though no doubt they will strive to retain their lead by making up in quality what they will lose in quantity.

These two lines of development—atomic energy and automation—show that knowledge is no longer growing slowly and steadily, along traditional

lines, but is advancing stormily and quickly, upsetting traditional classifications and concepts. It is becoming less and less possible to consider a particular development from the point of view of a single scientific discipline. First came the need for co-operation between the various natural sciences and engineering; then some borderline fields were added to it; now we also require the help of economic, psychological and social disciplines. The rate of introduction of automation, for example, will be determined by economic and social factors—profitability, capital availability, the technical and administrative skill of management, and worker reactions—much more than by the development of technological processes, the main elements of which are already in existence.

Great tasks thus await the social scientist. Welcome or deplore as we may the material civilization which is being built by science, there is no retreat from it. Our task is therefore to control the colossus which has been growing since the beginning of the Industrial Revolution and to ensure that he becomes our servant and not our master. To do this we must know much more about the nature of this colossus and how he will grow, and much more about our own nature and needs. The social sciences at their present stage can do little more than pose the problems; these are so formidable as to challenge the keenest minds to create new methods with which to attack them. In this third phase of industrial evolution, the social sciences have perhaps a more important role to play than the natural sciences and technology themselves.

The Peaceful Uses of Atomic Energy

BIOLOGY AND MEDICINE AT THE GENEVA CONFERENCE (8-20 August 1955)

by

JEAN COURSAGET

The following article gives a brief summary of the principal biological and medical uses of nuclear energy, as described in papers submitted to the Conference on the Peaceful Uses of Atomic Energy, held at Geneva from 8 to 20 August 1955. The author, a Doctor of Physics and professeur agrégé des Facultés de Médecine, is head of the biological branch of the French Atomic Energy Commission.

It is true that the new information made available to biologists at the Geneva Conference was far less than was forthcoming in some other fields, such as nuclear physics and the technology of reactors and fissile materials. This was only to be expected, since the results of biological and medical research are, in the majority of cases, readily made public. However, the papers submitted in the biology section—of which there were about 300—did reveal the extent to which industrially produced nuclear energy is being applied, and the scale of the problems to which this gives rise.

These applications and their related problems may be classified under two main headings—the use of isotopes as tracers, and the biological effects of radiations.

Reactors and particle accelerators are now turning out large quantities of artificial atoms, most of which are isotopes—homologues—of natural elements. These isotopes, which may to some extent be regarded as by-products of the newly established nuclear industry, offer immense possibilities for the study of physics and chemistry; they put ingenious methods of testing and control at the disposal of industry; above all, they serve as a unique instrument of biological and medical research. For 'tracer' isotopes act as spies on the living body, making it possible to follow the course taken and the changes undergone by a 'labelled' molecule as it moves, in perfect concealment, among other molecules of the same kind.

But the release of nuclear energy on an industrial scale has as its inevitable corollary the emission of penetrating radiations and the abundant production of radio-active substances. The absorption of these rays by the tissues of the

body, the swallowing or inhalation of radio-active substances, induce structural and functional modifications of the living cells. These are likely to lead to serious disturbances—culminating, in some cases, in the death of persons exposed to such radiations, or perhaps doing irreparable damage to the hereditary factors such persons have to transmit. The general public, though insufficiently informed of the nature and gravity of this danger, has expressed its natural alarm. The Geneva Conference did good service here, by bringing together many viewpoints and thus clarifying the extent of our knowledge concerning the biological effects of radiations, and making it possible to compare the measures adopted in different countries to protect workers and safeguard the population.

THE USE OF ISOTOPES AS TRACERS

An essential characteristic of living beings is their chemical autonomy. No variations of environment or nutrition can alter their specific chemical composition. This stability considerably hampers us when we employ the traditional methods of chemistry to study the transformations entailed in the construction of new cells and in the replacement of the constituents required for the production of energy or the maintenance of glandular secretions.

In man and animals this study is further complicated by the fact that their food consists mainly of substances similar to those normally to be found in their tissues. Once assimilated, therefore, these products are no longer discernible, and we cannot follow the way in which they are utilized.

This situation was completely transformed some ten years ago when it became possible to make use of isotopes, by means of which a wide range of molecules could be 'labelled'. For these 'artificial' molecules have the same chemical properties as the corresponding natural molecules, and behave in exactly the same way when introduced into a living organism. They differ to some extent, however, in their physical properties—their mass is slightly greater and they give off radiations—and thanks to highly sensitive detectors it is possible to isolate the 'labelled' molecules from their natural homologues.

It was very soon discovered that practically all the components of any living body undergo constant renewal, and that the permanent character of its chemical composition is due, not to a real stability, but to a balanced relationship between synthesis and decomposition, between the products entering and leaving the body, between travel through the membranes in one direction and in the opposite direction. The isotope method does more than supply direct proof of this unceasing exchange of matter and energy; it reveals all the stages—even the briefest—in the process; and what is perhaps yet more important, it makes the kinetic conditions clear. The rate of

molecular 'turnover' is a fundamental fact, and it has been discovered to be, in many cases, much more rapid than was supposed. Every day, for instance, about 10 per cent of blood proteins are destroyed and replaced by new molecules. Some components are even more unstable—for example the glutathione and the potassium in the cells of the uriniferous tubes, which are entirely replaced every few minutes. The most complex and specific molecular structures built up by living beings from simpler elements in their surroundings have only an ephemeral existence, and the permanence of their characteristics results from the perpetual rearrangement of an organization which is never in repose.

The basic biological sciences, particularly biological chemistry and physiology, have drawn the chief benefit from the use of isotopes as tracers. Armed with those valuable aids, biochemists are elucidating the mechanism of reactions and discovering new ones, while physiologists are continually adding to our knowledge of the circulation, the diffusion of substances, of their manner of traversing the membranes, and of the conveyance and metabolic behaviour of substances of great biological interest, such as hormones and vitamins. The few papers on the subject submitted at Geneva could not claim to cover this vast field of basic research. They gave only a faint idea of the stimulating effect produced in biochemistry and physiology by the introduction of the nuclear 'tracers' method.

Relatively more time was given to describing the applications of this method to medicine and agriculture, which were fairly extensively dealt with.

MEDICAL APPLICATIONS

In medicine, a distinction must be drawn between clinical tests, used in diagnosing illness or ascertaining the condition of a patient, and physiopathological research, which comes within the field of basic physiological investigation.

Clinical Applications

Radio-iodine 131 has an outstanding place here; it has become indispensable to the diagnosis of thyroid troubles, and every year now tens of thousands of patients undergo functional examination by means of radio-active iodine. Methods of performing this clinical test vary widely, but it nearly always consists either of ascertaining in what proportion and at what speed the radio-active iodine is taken up by the thyroid gland, or of assessing the quantity of hormones synthesized by the gland as a result of its introduction. In 24 hours a normal gland takes up between 10 and 40 per cent of the iodine administered.

Unfortunately, we know of no other example of such a selective uptake by an organ of a substance introduced into the body. However, an intravenous injection of radio-active iron, preferably iron 59, in a chemical form similar to that of plasmatic iron, will to a great extent be used up in the bone-marrow to form red corpuscles, and gradually disappears from the plasma. Most of it reappears in the haemoglobin of the red blood corpuscles in the circulatory system, and, just as the uptake of iodine by the thyroid enables us to observe the activity of that gland, so the uptake of radio-iron by the medullary cells may provide an excellent means of testing the activity of the erythropoietic tissues.

Certain tumour tissues too, owing to their functional specificity or to the impaired condition of the neighbouring tissues, take up certain substances at an appreciably higher rate than does the surrounding healthy tissue. This property has been made use of in diagnostic tests carried out with radio-active products. In some cases, for instance, the position and size of a brain tumour can be discovered by administering a suitable radio-active product, such as di-iodofluorescein or iodized albumin serum, and then studying, by means of an external detector, the distribution of gamma rays around the skull. If the tracer substances are labelled with isotopes which give off positive electrons—such as those of copper 64, which emit two quanta of gamma rays travelling in two opposite directions—it becomes possible, by an ingenious calculation of coincidences, to define still more precisely any area in which the tracer substance is concentrated. In many cases of brain tumour, however, the co-efficient of concentration of the substances at present utilized is too low, and the isotopes cannot provide any reliable information.

Phosphorus 32, administered in the form of phosphate of sodium, is extensively taken up by most tumours, phosphorus being indispensable to secretion of the nucleic acids which play a leading part in the process of cellular growth; but phosphorus 32 gives off only beta rays, whose electrons cannot penetrate more than a centimetre or so of tissue. Brain tumours cannot be detected through the skull, but, during an actual operation, a brain probe counter can be used to discover the size of the tumour and provide the surgeon with valuable information. Other tumours can be detected or investigated with the help of radio-phosphorus, and one paper submitted to the Geneva Conference dealt with the diagnosis of intra-ocular tumours by this method.

Radio-elements are also used in clinical practice for measuring liquid spaces and studying the dynamic characteristics of the circulation of the blood. The liquid spaces are easily measured by the dilution method—injecting a labelled sample of a substance which spreads through the space to be investigated and is only very slowly eliminated therefrom. Once the diffusion is completed, all that is necessary is to draw off a sample of known volume and to ascertain what quantity of the tracer substance it contains.

The use of iodized albumin serum, for instance, makes it possible to measure plasmatic volume, that of heavy water, or tritiated water, makes it possible to measure the total quantity of water in the body. This method can also be applied to the blood corpuscles: chromium 51, for example, which is readily taken up by the red corpuscles, enables the blood volume to be rapidly and precisely measured.

One of the most important characteristics of the isotope method is that it lends itself to the study of dynamic phenomena; and the investigation of the circulatory system offers a convincing example of this. The injection into a surface vein of a small quantity of albumin serum labelled with iodine 131 makes it possible to determine cardiac activity and follow its modifications—for instance in heart cases—simply by measuring the gamma rays emitted by the heart. Similarly, by placing two detectors on a blood-vessel, the flow of blood can be estimated, thus supplying an important factor in diagnosis or prognosis.

The method of radio-activation was also described at the Geneva Conference. Under the influence of certain radiations, such as neutrons, various elements contained in the tissues become radio-active, which makes it possible to discover their presence and ascertain their amount. The Royal Cancer Hospital, London, working in collaboration with the Atomic Centre at Harwell, found it possible in this way to measure the gold content in the hepatic tissue of patients being treated with colloidal gold, though this was no more than a few millionths of a gram per gram of tissue. Other experiments were made to discover the amount of arsenic in the skin of patients suffering from arsenical poisoning, and the method is capable of further extension.

Another clinical application may also be mentioned, though in this case the isotopes are not used as tracers; this is the utilization of radio-thulium 170 or, better still, radio-xenon 133, to provide rays for radiographic purposes. These radio-active sources cannot be expected to supply radiations as intense as those given off by a modern X-ray generator, but they have the great advantage of simplicity. They operate without electric current and this fact, together with their small bulk, enables them to be used in cases where an X-ray tube cannot be employed. For instance, they make it possible to photograph the base of the spinal column, including the sacrum, the radio-active source being placed inside the rectum. In dental radiography, too, it may sometimes be useful to have a source of radiations which can be put inside the mouth.

Physiopathological Studies

In addition to these clinical applications, the use of nuclear tracers has made possible a considerable expansion in medical research. The digestive and

assimilative processes, which involve both conveyance and metabolic transformations, offer a wide field of study where isotopes can often do good service. Thus at Geneva interesting papers were submitted on the expulsion of radio-active carbon dioxide after the injection of substances labelled with carbon 14, on the excretory function of the liver, and on the mechanism of the secretion of hydrochloric acid by the stomach.

Interesting research has also been devoted to problems of circulation and to the conditions attending the passage of substances through the biological membranes; here, investigation has dealt chiefly with the distribution of fluids among the different compartments of the body and the process of their 'replacement', with the exchange and conveyance of ions in correlation with their physiological functions, with the dynamics of the circulation and with the relationship between athero-sclerosis and serum lipoproteins.

There are several gaseous tracers which can be used to measure the respiratory capacity of the lung: nitrogen 15 is probably the ideal tracer, as the air we breathe consists chiefly of nitrogen, but since that isotope is not radio-active a mass spectrometer is required in determining it; one paper read at Geneva showed that it is perfectly possible to use tritium (radio-active hydrogen). Measurement then becomes fairly simple and lends itself to a common method of diagnosis.

In haematology, isotopes can render outstanding service. They make it possible to study biosynthesis and the degradation of haemoglobin both in normal and in pathological conditions. (Two papers were submitted on this subject.) They offer a means of measuring the replacement rate and the life-time of blood cells, especially the red corpuscles, and of tracing their variations in cases of blood disorders. An approach has also been made to the metabolic and physiological study of a number of factors involved in haemopoiesis, haemolysis and coagulation.

The tracer method has proved extremely valuable also in endocrinology. Much research, in which the radio-active isotopes of iodine are employed, is being devoted to the physiology of the thyroid gland and to the metabolism of the thyroid hormone and of iodized organic compounds. Some writers have drawn attention to the part played by genetic factors in cases of myxoedema; others have tried to determine the mutual relationship between the functioning of the thyroid gland and the nervous system or the sex hormones. But though the thyroid is particularly suitable for investigation by isotopes, it is not the only endocrine gland to which such investigation can be applied; in particular, the isotopes of carbon and hydrogen have made it possible to study the metabolism of steroids. Generally speaking, the nuclear tracer method, owing to its accuracy and sensitiveness, is ideally suited to the study of the particularly complex problems connected with the biological behaviour of hormonal substances, minute quantities of which may produce such powerful effects.

In pharmacology it has been possible to follow the course of a large number of labelled medicines as they travel through the body, and the information obtained helps to explain how their effects are produced. Among the papers at the Geneva Conference were some which dealt with the metabolism of hypnotic drugs, of the sulphones used to combat leprosy, and of terramycine.

The isotope method has also been adopted in bacteriology, parasitology and epidemiology, and the subjects discussed at Geneva included bacterial metabolism, the tracking down of the parasites responsible for the chief endemic diseases, and the labelling of the haematozoa-carrying mosquitoes which convey malaria. Almost every branch of medicine was, in fact, represented, and very few methods lend themselves to application in so wide a field of medical resarch.

AGRONOMIC APPLICATIONS

A comparatively large proportion of time at the conference was devoted to agricultural problems and their study with the help of isotopes.

Much research has been devoted to soil science, to the relationship between plant and soil, and also to the biochemistry and physiology of plants. This has shown that the isotope method can be extremely useful in combating noxious organisms.

Soils and Fertilizers

Radio-phosphorus has facilitated extensive study of the conditions attending the use of mineral phosphorus by roots. This seems to indicate, in particular, that there is no connexion between the proportion of soluble phosphates present in a particular soil and the quantity of PO_4^{---} ions absorbed by the plants which grow in it.

Different soils can take up widely varying quantities of soluble phosphates, and the fraction which the plants may assimilate cannot be measured solely by chemical analysis. Moreover, plants differ from one another in their capacity to extract phosphorus from the soil. In roots, phosphorus is partially combined with iron in a complex form, and the concentration of iron is thought to influence the uptake of phosphorus.

The conditions governing the absorption of iron and zinc have also been studied with the help of iron 55 and zinc 65. It has been shown that these metals are much more satisfactorily absorbed when combined with chelating agents, such as ethylene diaminotetracetic acid. This facilitates exchange between the solution and the soil, and the metal is more regularly distributed.

Similarly, cobalt 60 has been used to trace the distribution and fixation

of that metal in various soils and to discover how it is absorbed by plants. Research carried out in Russia has shown that in this case, again, the fraction which can be assimilated is determined by the 'dynamic balance' between the cobalt ions taken up by the soil complexes and the free ions present in solution. The addition of small quantities of cobalt to the soil was found to have a definitely favourable effect on the yield of certain plants, such as barley, especially in an acid soil which had been treated with lime.

Little is known as yet about the way in which ions are absorbed by plants. It has been found that this involves conveying systems by which the ions are temporarily fixed, and that the fixation points have a particular affinity to certain ions. With the help of various radio-active isotopes, including sulphur 35, strontium 89, bromium 82 and rubidium 86, it has been shown that the ions enter the roots in two stages, governed by two very different mechanisms. First comes a rapid, reversible exchange, often completed in less than an hour. This leads to an equlibrium—or even, perhaps, in some cases, to a state of equality—between the quantity of ions in solution in the soil and the quantity present in an 'outer' compartment of the roots, representing from 10 to 30 per cent of the total volume of those roots. An active process is then initiated to convey the ions into the 'inner' compartment. This is a much slower matter; the process continues for hours at an unvarying rate and does not lead to a state of equilibrium.

These few examples will show the great potential value of radio-isotopes to the study of mineral intake by plants. They have opened a way for research into the dynamic conditions governing the transport of ions, which cannot as yet be investigated by any other means.

Roots are by no means the only organs through which plants can absorb their mineral nourishment. Research, particularly in the United States, has shown that the leaves, branches, fruit and even the trunk of a tree can easily absorb mineral substances deposited on them. Thus, if we wrap the trunk of an apple tree in bandages soaked in a solution of potassium carbonate labelled with potassium 42, or of phosphoric acid labelled with phosphorus 32, we shall find, 24 hours later, that these radio-active elements have travelled a long way from their area of application—even in February, when plants seem to be hibernating and the temperature is below 0° centigrade. This has led to the perfecting of a winter treatment for mutilated or damaged fruit trees, by coating their trunks and branches with various compositions or nutritive pastes. But it is in relation to the leaves that this phenomenon is of outstanding importance, owing to its intensity and to the extensive surface over which absorption can take place. The upper and lower sides of the leaves are approximately equal in their capacity for absorption, and the leaves of a ten-year-old apple tree provide an absorbent surface of about 400 square yards. Isotopes have revealed that nitrogen, phosphorus and potassium are easily absorbed by the leaves and subsequently spread to all parts of the tree,

including the roots, at a speed comparable to that observed when the same elements are absorbed from the soil. Their distribution, too, is exactly the same—phosphorus, for instance, accumulates in both cases in the quick-growing meristematic areas. Calcium, on the other hand, is never found below the level of the leaf to which it has been applied.

The process of absorption is in no way affected by the opening or closing of the stomata, continuing by night as well as by day.

In the case of herbaceous plants, the use of folian fertilizers may in certain cases amount to 95 per cent, and the spraying of the leaves with nutritive substances is then found to be the most effective means of soil enrichment. At least 25 per cent of the phosphates required for the growth and ripening of fruit can be provided by spraying the leaves with phosphates at the right moment. In the case of nitrate fertilizers the position is even better, and it has been proved, with the help of carbon 14, that the penetration of urea, its hydrolysis by urease and the employment of nitrogen take place in conditions such that the entire quantity of nitrogen required by certain plants can be supplied by spraying the leaves with urea.

The contrary process has, incidentally, also been observed—the elimination, sometimes on a large scale, of certain plant constituents when the leaves were sprayed with water in a quantity equivalent to several hours of heavy rainfall. By this means it would be possible to extract between 2 per cent and 15 per cent of the radio-phosphorus and as much as 70 per cent of the radio-potassium contained in the leaves as a result of absorption through the roots. Some writers go so far as to consider that during rainy periods losses of this kind may be as harmful to crops as want of sunshine.

In studying agricultural conditions, it is important to discover the amount of humidity in the soil. Here, too, the radio-elements offer a neat and practical means of measuring humidity at different depths, without taking samples of the soil. The method consists of making what may be called a radiograph of the soil. A hollow aluminium cylinder, 2 inches in diameter and sometimes several yards in length, is thrust vertically into the ground. Into it is introduced, at the required depth, a radium-berylium source emitting fast neutrons. The neutrons are slowed down chiefly through their impact upon the hydrogen atoms of the water molecules contained in the ground in solid, liquid or gaseous form; moreover, the concentration of slow neutrons in the neighbourhood of the source stands in direct relationship to the concentration of water molecules contained in the ground. A thin strip of indium or rhodium placed in the tube, near the source, becomes radio-active through the action of the slow neutrons, and all that is then necessary is to measure its activity. Apparatus of this type, constructed in Canada, was described in detail at Geneva.

Plant Physiology

The undoubted interest of this investigation of soils and fertilizers must not lead us to forget that plant physiology is still one of the most profitable fields of application of the nuclear tracer method. The movements of substances within the plant, and their various transformations, offer unlimited scope for research.

Few papers, however, dealt with the phenomena of conveyance, apart from the movement of ions in the roots. Russian authors showed, chiefly through the use of carbon 14 and nitrogen 15, that, whatever the position of a leaf on its stem, the substances always begin by travelling down towards the roots, through the phloem vessels. Measurements applied to pumpkins, sugar-beet and various other plants have demonstrated that this movement takes place at a speed of between 70 and 100 centimetres an hour. Transformations take place on the way—such as the production of saccharose from fructose and glucose as the result of a phosphorylation reaction. The movement in the contrary direction, towards the young shoots and the fruits, proceeds rather more slowly, at a rate of 40 to 60 centimetres an hour. In some trees, water travels through the xylem vessels at a much quicker rate, which may exceed 10 yards an hour.

In the United States, interesting research has been carried out concerning the circulation of the sap in various varieties of oak, the tracers used being iodine 131 in the form of sodium iodide, rubidium 86 in the form of rubidium carbonate, and bromium 82 in the form of potassium bromide. The radio-active solutions were applied to a groove cut round the base of the trunk, and it was found that on a sunny day the radio-isotopes took less than 20 minutes to reach the branches and topmost leaves of oak trees 50 feet high, so that they were rising at a speed of about a yard a minute. At night, owing to the darkness, the lowered temperature and the relative increase in humidity, the pace slackened to a few centimetres per minute; in winter it dropped to one centimetre per minute.

This method has revealed natural root grafts in forests by the appearance of radio-active substances in neighbouring trees. As many as 50 oaks are sometimes found to be linked in this way. Circulation in the roots involved in this anastomosis may quite well be reversed, and some trees 'adopt' part of their neighbours' roots. This property is by no means confined to the variety of oak studied on this occasion (*Quercus ellipsoidalis* Hill). It would seem that spontaneous root grafts are still commoner among some other trees, such as aspens.

This state of things has its drawbacks from the point of view of forestry, for it may help to spread disease. This has been demonstrated by labelling the spores of a fungoid parasite (*Endoconidiophorafagacearum* Bretz) with silver iodide $Ag^{110}I^{131}$, by repeated immersion in radio-active solutions of

silver nitrate and sodium iodide. Despite the frequent obstruction of th vessels during the disease, the radio-active spores injected into the sick tr usually take little time to travel through the grafts and invade the health neighbouring trees.

The building up of organic substances by plants is a subject of natur interest, since it enables the energy emitted by the sun to be transforme into chemical energy, and is essential to the nutrition of humans and anima alike. The mysteries of photosynthesis are by no means solved, but some o the reports submitted at Geneva bore striking witness to the importance o the results achieved through the use of isotopes. American investigators mad an outstanding contribution on this subject. Experiments carried out wi unicellular green algae—chlorella or scenedesmus—were planned in such way that for a very brief period (from one to 60 seconds) these algae use carbonic acid labelled with carbon 14. At the end of whatever period wa chosen for this exposure, the algae were plunged into boiling alcohol to arre the enzymatic processes, and any constituents which might have absorbe the radio-carbon were carefully isolated by chromatography. Their specifi radio-activity was then ascertained and, if necessary, a chemical degradatio was undertaken, to determine the position of the radio-carbon in th molecule. The authors of the report had thus been able to follow step b step the various stages of the incorporation of carbonic acid in the chemica constituents of the plant, and were able to establish the chain of reaction leading from the carbonic acid to the pentoses by way of phosphoglyceri acid and aldehyde. They also discovered that the carbonic acid acceptor wa the 1-5 di-phosphoribulosis, which could itself be regenerated from th phosphoglyceric aldehyde, so that this whole series of transformations appear to constitute a cycle owing its inception to light, which provides the quantum of energy essential for the regeneration of the catalysts involved in two point of the cycle. If this regeneration is brought about by some other means, th cycle takes place in the dark and the sugars are then manufactured without the help of the energy of light.

These results are not, of course, sufficient to solve the very complex prob lems of photosynthesis. Indeed, they shed but little light on the essential point the manner in which the quanta absorbed at the level of the pigments are utilized. But they make a remarkable contribution to an understanding of th way in which carbonic acid is used, and serve as a brilliant illustration of th potential value of nuclear tracers in the field of metabolic transformations.

Papers were submitted by other authors, who had studied photosynthesis from a different angle. In the U.S.S.R., for instance, scientists have tried to establish a connexion between photosynthesis and the physiological processes which take place in other parts of the plant, especially in the roots—for the nature of the substances built up during photosynthesis varies according to the physiological circumstances of the plant.

Russian research workers also described the study of nitrogen metabolism in plants, carried out with nitrogen 15. All the nitrogen of the constituent proteins undergoes rapid replacement, at the rate of about 20 per cent per day. The rate of these transformations is therefore comparable to that of the replacement of plasmatic proteins in animals. The nitrogen in chlorophyll is equally labile, but we do not know whether there is any connexion between the changes evidenced by the exchange of the nitrogen atoms and the essential role played by pigment in the absorption and utilization of the energy of light. In the roots these processes take longer, though only 15 minutes are required to transform mineral nitrogen into amino-nitrogen, and a few hours for it to appear in the proteins or the chlorophyll.

The role of chloroplasts in cell metabolism is another interesting subject for scientific investigation by means of radio-isotopes. These cell structures contain a great number of multivalent enzymatic systems and remain capable, after extraction from the living cytoplasm, of carrying out a wide variety of chemical operations. A veritable micro-laboratory, they ensure the oxidation of fatty acids, the incorporation of phosphorus into the phospholipids, and even a certain degree of protein synthesis.

Parasitology

Isotopes have also been used with good results in insect and parasite control. In the first place it is possible to label insects, worms and even the spores of fungoid parasites, with radio-elements and thus study their behaviour, their evolutionary cycle, the distances they travel, the routes they follow during migration, or the conditions in which they hibernate. In Canada, for instance, active research is being devoted to mosquitoes, flies and grasshoppers. Flies and mosquitoes can be easily labelled by dipping their larvae in aqueous solutions of radio-phosphorus with a strength of about one-tenth of a micro-curie per cubic centimetre. Grasshoppers need only be fed for a few hours on corn sprinkled with a solution containing one millicurie of phosphorus 32 per 100 cubic centimetres. In the case of worms, a gamma ray transmitter must be used to detect their presence through a certain depth of soil; and it is impossible to adopt 'biological' labelling, for the elimination of the tracer substance in excrement might lead to errors. All that was done at first was to attach to the surface of the body a slender thread of cobalt possessing a radio-activity of about 20 microcuries. But as every time the worm sloughed its skin, it shed the tracer as well, it was found necessary to insert the cobalt thread into the body. This makes it possible to follow the worms as they move about and to study their living conditions. In an ingenious piece of apparatus described at Geneva, the Geiger-Muller counter, which detects gamma rays, is made, to follow, at ground level, by a servo-mechanism the worm's movements through the soil, and a reading can be taken at any

moment to ascertain the position and depth the creature has reached.

Isotopes are yet more effective in revealing the biochemical behaviour that the movements of these various parasites, and the information thus obtained is an aid to the discovery or improvement of parasiticides. In particular, the study of adaptation and acquired resistance confronts research scientists with a number of problems which isotopes can help to solve.

The same applies to the metabolism of the insecticides, fungicides and weed killers which are used on such a large scale nowadays; the substances are usually absorbed by the plants, to which they must not be toxic. Thereafter, however, they generally undergo transformations which may produce matter poisonous to human beings or animals.

Zootechnics

The breeding of domestic animals is another field in which isotopes are doing remarkable service. Particular attention was paid at Geneva to nutritional problems. The introduction of tracers into various types of fodder enables their respective food-values to be assessed, and this naturally leads to more rational feeding, resulting in increased productivity.

Conditions of growth govern meat-production; milk, too, is a basic human food and it is important to discover the chain of reactions which lead to its formation. Isotopes have made it possible to identify most of the intermediate stages and to investigate means of speeding them up. They are thus helping towards the discovery of optimum conditions for the abundant production of high grade milk.

Isotopes have also been used to solve certain special problems connected with the breeding of domestic animals. In particular, phosphorus 32 has elucidated the process of spermatogenesis and the behaviour of spermatozoids.

Various aspects of the development of aquatic fauna have also been studied. In the first place, the migration of fish in rivers, lakes and seas has been followed by attaching radio-active tracers to their bodies. By similar methods it is possible to study the strength of the intermingling currents which maintain the water supply. The most important investigations, however, are probably those dealing with the production of organic substances, upon which the development and multiplication of aquatic life in the last resort depend. By taking samples of water at various depths and adding to them a little sodium acetate, labelled with carbon 14, scientists have succeeded in calculating the intensity of the syntheses effected by the phytoplancton and by aquatic plants. With the help of other isotopes, they have been able to estimate the rate of replacement of mineral and organic substances, and have discovered, for instance, that bacteria play an extremely important part in this process. The results already obtained suggest that the biosynthesis which takes place in the ocean could be of considerable value

in producing food for human beings and animals; but they also show that its possibilities are at present being very largely wasted. It is to be hoped that the growth of our scientific and technical knowledge will one day make available considerable sources of nutrition, adequate perhaps to the needs of the world's ever increasing population.

BIOLOGICAL EFFECTS OF ATOMIC RADIATIONS

Atomic radiations result from nuclear reactions. They consist of electromagnetic rays of very high frequency, known as gamma rays. Their power to penetrate matter exceeds even that of X-rays, and the quantum of energy they transport is usually in the neighbourhood of a million electron-volts (M.E.V.). The different elementary particles which contribute to the atomic structure may be discharged with energy quanta which are also often very high. These are the electrons, protons, neutrons or associations of such particles. For instance, the alpha rays emitted by large numbers of heavy radio-active atoms consist of four elementary particles—two protons and two neutrons.

A characteristic common to all these rays is that they produce ions in the matter they traverse, especially in living tissue. For this reason they are known as ionizing rays. X-rays, and ultra-violet rays with a short wave-length, may also produce ions in the tissue they traverse, but the quantum of energy they transport is much weaker, and the ionizations which result are much fewer.

Atomic radiations, when passing through tissue, bring about changes which radio-biology is striving to define and to connect with the *primum movens*—the absorption of a quantum of energy by a molecule of the living matter. These changes are sometimes irreversible, and may then cause permanent injury to the affected cell, or lead to degeneration and necrosis. Atomic radiations may, therefore, be dangerous for man and for living beings, especially as none of our senses can perceive their presence and warn us of the peril. Stringent protective measures must consequently be adopted, especially in atomic centres.

On the other hand, these radiations, whether emitted by atomic reactors, particle accelerators or the radio-elements prepared therein, have lent themselves to interesting applications in medicine, agriculture, the pharmaceutical and the food-processing industries. The study of the biological effects of radiations thus leads to the consideration of certain of their aspects, all of which were examined at the Geneva Conference.

RADIO-BIOLOGY

The formation of ions in cells is accompanied by chemical changes which in turn, produce modifications in metabolic or physiological activity. In most cases these changes cannot be perceived immediately after the irradiation. We have to wait until the biological processes, following their course, reveal—by a kind of amplification—the primary lesions caused on a molecular scale. The extent of such radio-biological action can usually be gauged when a cell divides for the first time after irradiation. It is thus possible to irradiate bacteria with as much as 60,000 roentgens, without afterwards observing any notable decrease in respiratory or glycolytic activity during a period equal to that of a normal reproductory cycle. Yet at that strength the biological damage done is such that only about one cell in ten thousand will remain capable of indefinitely multiplying itself. The majority will die at the moment of the next cellular division, or in any case after a few such divisions. As long as they are still alive, however, their metabolic and physiological properties remain practically normal. In particular, they can act as hosts to viruses whose development requires the integrity of all the enzymatic systems of their host.

These facts may be partly explained by the action of the ionizing rays upon the chromosomes or genes. For while damage to minor features of cellular metabolism can be repaired during the processes of renewal, lesions of the genotype are known to be irreparable.

As long ago as 1927 H. J. Muller proved that X-rays could cause mutations, and the same is true of all ionizing radiations. We know today that a single alpha particle can split a chromosome, and that mutations are usually due to the action of a single particle. This being so, the biological effect produced on a group of cells is proportionate to the strength of the irradiation, and there cannot be any lower limit. Every irradiation, however weak, may be expected to leave a permanent mark on the irradiated cell and on any descendants of that cell. Moreover, biological action is unaffected by the timing of the irradiations, successive exposures having a cumulative effect.

Since in most cases the lesions do not become perceptible until the next cellular division takes place, their period of latency will be the longer, the slower the rate of replacement of the cells. Irradiation of the meristematic cells of vetch roots, which divide approximately every 24 hours, will make it possible to observe after only a few hours the ruptures which have taken place in the chromosomes during irradiation. In the case of the epithelial cells of the lens, a period of about ten days must elapse. Replacement of the cells in the thyroid takes place so slowly that when that gland is irradiated the results will not be observed for several months. Lesions caused in a grain of corn will become apparent during germination, even should that be retarded for a number of years.

Another important fact to which the attention of radio-biologists has long been directed, is the widely varying sensitiveness to ionizing rays which is displayed by different types of cell. Some cells, generally forming part of rapidly growing tissue, can be destroyed by about 100 roentgens, while others, such as amoebae or paramecia, seem unaffected when irradiated by several hundred thousand roentgens. A still more surprising fact is that, if cells in a vetch root, about a centimetre from the tip of the root, are irradiated with a dose of 200,000 roentgens, this will cause only a slight and temporary reduction in their rate of growth. Yet 24 hours previously, when these cells were in the apical meristem, they could have been killed by a dose of only a few hundred roentgens. So that the transformations taking place in these cells within a space of 24 hours have reduced 1,000 times their sensitivity to radiations.

It is also well known that sensitivity to radiations varies considerably in the course of the mitotic cycle, and it is usually during the prophase that the cells are most vulnerable.

Neither cytology nor histology can at present explain these phenomena. At Geneva, American scientists described how, by using proton micro-beams a few microns in diameter, they had succeeded in carrying out partial irradiations of cells and in observing, from the morphological viewpoint, the evident differences in the sensitivity to radiation of different cell structures, especially those which play a part in cell division. This new method of investigation should help to explain the diversity observed in the reaction of living cells to ionizing radiations.

Repeated attempts have been made to use the study of the chemical and biochemical processes caused by irradiation as a basis for the etiology of cellular lesions due to rays. Radio-chemistry has made rapid progress and it is now known that, except in the case of particles which produce very dense ionization all along their trajectory, the direct action of radiations plays a comparatively minor part. By direct action, we mean the destruction of a molecule consequent upon ionization, or upon the excitation caused by its direct absorption of a fraction of the energy transported by the incident ray. There is reason to believe that the majority of cellular lesions result from secondary chemical transformations produced by the ions or by the free radicals, most of them formed from water molecules, which, as we know, abound in the cells and tissues of living beings. For in water the ionizing radiations produce positively and negatively charged molecules, H_2O^+ and H_2O^-, which rapidly split into H^+ and OH^- ions on the one hand, and into H and OH free radicals on the other. These radicals show a high degree of chemical activity, and disappear very rapidly by reacting with neighbouring molecules. Moreover, if the living matter contains molecular oxygen O_2, as in the case of cells living in aerobic conditions, a hydrogen peroxide is formed by reaction with the H radicals, and decomposes in its turn according to the

reaction: $2HO_2 \longrightarrow H_2O_2 + O_2$, thus liberating peroxide of hydrogen in the tissues, with the inevitable oxidizing and toxic effects.

Various experiments have shown that the sensitivity of cells to X or gamma rays is often affected by variations in the partial pressure of the dissolved oxygen, just as certain chemical reactions are produced in an aqueous environment.

It has also been definitely established that the distribution of the primary ions, and consequently of the free radicals, to a great extent determines the relative biological effectiveness of the different types of radiation. For instance, X-rays of 200 kilovolts and deuterons of 190 million electron-volts form, in tissue, about 20 ions per micron and have approximately the same biological effectiveness. Low-energy protons, which may form as many as 2,000 ions per micron, and alpha particles, which can produce up to 4,000, have a much stronger biological effect.

But a grasp of these initial phases and of their influence constitutes only a very small step towards the understanding of radio-biological phenomena. For one thing, the brief existence of the free radicals makes it difficult to investigate the reaction they set up. British scientists said, however, at Geneva that they intended to study this question by using pulsed radiation sources and short-wave spectroscopes.

Regarding the subsequent biochemical reaction, only disconnected scraps of knowledge have been acquired. Attention has, for instance, been drawn to the fragility of the sulfhydryl groups (SH) in relation to oxidizing agents. These radicals play an important part in metabolism, and the radiations produce strong oxidizing substances.

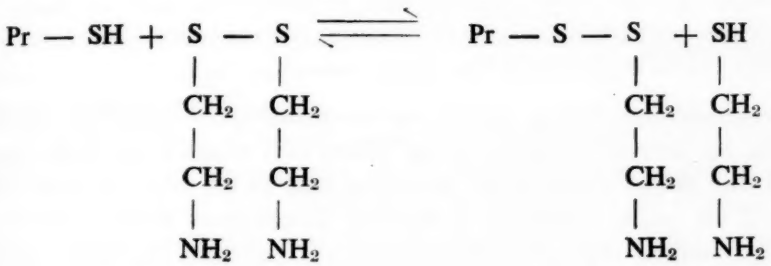
Moreover, certain substances such as cystein and cysteamin which protect living organisms against the effects of radiation, have their own sulfhydryl groups (Table 1), and it was natural to assume that they acted as chemical competitors of biological substances having the same chemical group.

TABLE 1. Radio-Protective Chemicals

Cystein	$NH_2 - \underset{\displaystyle COOH}{\underset{\displaystyle \vert}{CH}} - CH_2SH$
Cysteamin (β — Mercoptoethylamin)	$NH_2 - CH_2 - CH_2SH$
Cystamin	$NH_2 - CH_2 - CH_2S$ $\vert$ $NH_2 - CH_2 - CH_2S$
β — Aminoethylisothiuronium	$NH_2 - CH_2 - CH_2 - S - C(=NH)(NH_2)$
Tyramin	$NH_2 - CH_2 - CH_2 - C_6H_4OH$

Experiments carried out in Norway and described at Geneva have, however, shown that 90 per cent of the cystamin or cystamin injected into an animal is taken up by the proteins, particularly the intracellular proteins.

This uptake, which requires the presence in the molecule of proteins of free hydroxyl groups, is thought to correspond to the reaction:



The action of these protecting agents does not therefore appear to consist, as had been supposed, of direct competition with regard to oxydation. Moreover, in the case of man and other mammals they reduce the toxic effects of radiation only to a moderate degree, amounting, at the most, to a factor of 2.

Furthermore, while oxidation undoubtedly plays a leading part, many other biochemical modifications are to be noted. One of the most important, perhaps, is the slowing down or interruption of the biosynthesis of the nucleic acids, to be observed in many vegetable or animal cells when irradiated with between 100 and 1,000 roentgens. However, despite the essential part played by the nucleic acids during cell division, the absence of the biosynthesis of those substances can hardly account for the radio-lesions which affect the structure of the chromosomes, for such lesions appear even if irradiation is carried out at a late stage of the reproductive cycle, when synthesis of the nucleic acids has been completed.

Consequently, we are far from complete understanding of the chain of chemical and metabolic events which connects the structural and functional disturbances in irradiated cells with the initial phenomenon of their absorption of energy in the form of rays.

In complex multicellular organisms, the radiobiological effects result from lesions suffered by the different cells. They depend not only on the radiosensitivity characteristic of various types of cells, but also on their rate of multiplication, the histological structure of the tissue and the local conditions of circulation and oxygenation. They also vary according to the function of the damaged cells and according to the factors governing the interdependence of the systems and organs concerned.

DANGER OF RADIATION AND PROBLEMS OF PROTECTION

Man, like other mammals, is subject to two types of radio-biological action—that which appears in the individual exposed to radiation, and that which may affect his descendants. The former are lesions of the somatic cells, while the latter results from damage to the germinal cells.

Somatic Lesions

An irradiated person may present various pathological symptoms which will depend on the dose received, on the period over which it has been administered, and on the extent of the area irradiated. In the event of acute irradiation of the whole organism, a series of disturbances which have by now become familiar will manifest themselves, if the dose has been sufficiently large. A very precise description was given at Geneva of the symptoms presented by certain American and Russian workers who had been accidentally exposed to doses of neutrons and gamma rays ranging from 12 to 450 roentgens. The toxic effects are revealed, after a period varying from a few hours to several days, by nausea and anorexia, often accompanied by vomiting and diarrhoea. The abundant elimination of amino acids in the urine at this stage gives evidence of a disturbed protein metabolism, but the condition of the patient does not become serious until two or three weeks have elapsed. The clinical picture is then dominated by phenomena of a hematological and infectious character. The temperature rises, and a condition of extreme weakness or lethargy develops. Energetic measures must be taken to guard against anaemia, leucopenia and medullary hypoplasia, more especially by stimulating the haematopoietic system. Purpura then frequently appears, haemorrhage takes place, and the fragility of the capillaries shows a notable increase. To prevent these developments, calcium chloride and vitamin K have been given to sufferers during the days immediately following irradiation.

Infection, which results alike from changes in the living tissue, from the failure of antibodies to develop, from leucopenia and perhaps also from changes occasioned in the bacterial flora, constitutes a serious danger to irradiated persons. The Russian sufferers were therefore treated with penicillin from the first few days. Towards the end of the second week they were given one gram of streptomycine a day, while the daily quantity of penicillin was doubled. Thanks to these measures, the lives of all the patients were saved, but some of them had to spend several months in hospital before being able to resume work.

Effects as serious as this need not be expected unless the entire organism has been exposed to radiation of a strength of about 100 roentgens. Certain disturbances may, however, result from radiation on a much smaller scale

Slight haematologic modifications may be produced in some people by only a few roentgens; but it is safe to say that below 10 roentgens the total irradiation of the organism will not give rise to any serious clinical disturbance at least at any early stage.

Partial irradiation is less dangerous than general irradiation. It may, however, become serious if it affects an important organ, or cells with a high radio-sensitivity. The absorption of radio-active substances may, therefore, have disagreeable consequences, especially if they are substances which have a special affinity for some particular organ and if their rays cause intensive ionization of the cell tissue.

In addition to early accidents, there is a danger that retarded radio-biological effects may result from a single irradiation, from a limited series of irradiations, or from constant exposure to small doses. In a report submitted to the Geneva Conference, American scientists declared that spermatogenesis in dogs exposed to a continuous external irradiation of 3 roentgens per week revealed serious disturbance at the end of a year, the number of spermatozoa being less than one-tenth of normal. In some cases, too, sudden changes in blood composition have been observed, long after irradiation, in persons or animals who had hitherto shown no sign of any radio-biological effect on their haematopoietic system.

Another fragile organ is the lens of the eye. The intense ionization caused there by accelerated heavy particles may initiate a gradual clouding; some ten years ago several research scientists, particularly in France, were affected by cataract.

But the most serious form of retarded threat comes from the effect of ionizing rays on the development of cancer. It will be remembered that there was formerly a high incidence of cancer of the lung among the German miners of the Schneeberg and among Czechoslovak miners in the Joachimstal area. These men were breathing air containing radon, to a probable amount of about 10^{-9} curies per litre. As it disintegrates, this radon produces solid products—themselves radio-active—which settle on the air cells of the lungs. It will also be remembered that radiologists and their fellow workers have often fallen victims to epithelioma or leucaemia.

Another example was given at Geneva: 13 children between 4 and 15 years old were admitted to the Argonne hospital in America with carcinoma of the thyroid gland. All 13 had, a few years previously, been given X-ray treatment for some mild affection of the thorax, such as swollen tonsils or cervical adenitis. The irradiation had ranged from 200 to 700 roentgens, and the average duration of latency had been 6.9 years.

Cancer can be caused in animals, such as mice, with a probability sometimes approaching 100 per cent, by the injection of radio-active substances. For instance, a single injection of radio-stronium, at the rate of 5 microcuries per gram of tissue, is sufficient to induce a malignant tumour of the bone a

few months later. Similar results are produced by what are called radio-mimetic chemical substances.

Despite these experimental possibilities we know little or nothing about the mechanism of this carcinogenic action, and are still at the stage of hypothesis. Caution is therefore required; the International Committee of Radiology bore this in mind when decreeing 0.3 roentgens per week as the maximum dose for workers continually exposed to radiation. This represents about one-tenth of the amount beyond which mild somatic disturbances begin. For the rest, irradiation of the whole body is rare, and this is an additional factor of safety.

It is true that we have not yet had time to estimate the long-term biological effects produced on man as a result of constant irradiation by this dose of 0.3 roentgens per week, which represents, over a period of 30 working years, a total of 450 roentgens. It may be that safeguards in this respect are less complete than against immediate risks; but in actual fact hardly any of the workers at an atomic centre are permanently exposed to the maximum dose.

The situation concerning the radio-elements is the same; the maximum quantity which can be absorbed or inhaled without danger has been carefully calculated for each of them, with due regard to their biological period and possible selective localization.

If these standards are adhered to, and if frequent and thorough inspection is carried out, workers exposed to radiation need fear no danger from its biological action. Those responsible for protective measures must never forget, however, that standards cannot be applied to all individuals without distinction, and that the results of physical measures must be interpreted in the light of our biological and medical knowledge, which unfortunately is still far from complete.

The Genetic Danger

Radio-mutations may appear in any of the cells in an organism, but those caused in the cells of the soma affect only the person who has been subjected to irradiation. Those caused in the germinal cells, however, affect the hereditary factors which we transmit to our children. For this reason, many people have expressed uneasiness about the genetic peril which might result from the expansion of the atomic industry and from experiments with nuclear weapons.

Highly qualified experts submitted reports to Geneva on this grave question, and a remarkable article by Professor Westergaard has already been published in this review.[1] Geneticists, confronted by the hard task of

1. *Impact*, vol. VI, No. 2, June 1955.

elucidating the mystery of the reproduction of living beings, realize the extreme complexity of the phenomena with which they are concerned. Scientific integrity compels them to admit the present limitations of their knowledge, and Professor Westergaard tells us how irritating they find the simultaneous plethora and inadequacy of their knowledge, which arouses anxiety without enabling them to define the danger with the desirable exactitude.

But though many points remain obscure, the present state of genetic knowledge provides a firm foundation for the assessment of the dangers involved in the use of atomic energy, and a starting point for measures to protect our descendants from inheriting disaster.

From the individual standpoint we know that, so long as protective measures are enforced, workers need have no fear that their immediate descendants will suffer from an abnormally high proportion of hereditary pathological disorders. For the frequency of gene mutations resulting from irradiation amounts to only about 2.2×10^{-3} per gamete and per roentgen. Consequently, the dose of 450 roentgens which would be absorbed over a period of 30 years by a worker constantly exposed to the maximum permissible dose of 0.3 roentgens per week could not produce more than about one new mutation per gamete. The average individual is heterozygous in respect of 7 to 8 natural mutations of a definitely unfavourable character—in other words, among the 15,000 or so genes he inherits, 7 or 8 may carry pathological disorders. It is true that the natural mutations we all have to transmit have already been subjected to selection and, on the average, probably represent changes less unfavourable than radio-mutations; but it is also true that they are far more widespread and that in the long run, provided irradiation is properly supervised, workers have much more to fear from their natural genetic inheritance than from any new mutations brought about by the rays to which they are exposed.

Radio-biological examination and treatment are, on the other hand, not exempt from danger; in particular, mention was made at Geneva of the serious disturbances which may affect the development of the embryo if the pelvic area is subjected, during the first fortnight of pregnancy, to a dose of X-rays amounting to a few hundred roentgens.

Any danger to the population as a whole would be due to an increase in the surrounding radio-activity, owing to the release of artificial radio-active products into water or air. The natural mutations due to molecular activity, chemical action or natural radio-activity are then augmented by those due to artificial radio-activity. It is our duty to ensure that the relative increase in the frequency of mutations is kept within certain bounds. Certain distinguished geneticists consider that above 25 per cent there would be an appreciable disturbance of the present conditions governing genetic equilibrium. Below 10 per cent such disturbance would not be perceptible.

The frequency of natural mutations is about 0.3 per gamete; we must therefore take steps to ensure that artificial radio-activity shall not cause more than 0.03 mutations per gamete. The frequency of radio-active mutations being about 2.2×10^{-3} per gamete and per roentgen, the maximum permissible dose for a large population would be about 15 roentgens.

The human body is normally exposed to cosmic rays and to the rays emitted by radio-active substances in the soil and in the body itself (Table 2). The dose varies according to the nature of the ground and the altitude; over a period of 30 years it amounts on an average to about 6 roentgens. Consequently the maximum permissible amount of artificial radio-activity is about double that of natural radio-activity. The total quantity of artificial radio-active substances so far distributed over the earth's surface, since the practical developments of atomic energy began to be applied, has not increased the amount of irradiation to which we are normally exposed by more than a few per cent. We therefore still have a very wide margin of safety. It should, incidentally, be emphasized that the present increase is almost entirely due to the explosions of atomic and thermo-nuclear bombs.

TABLE 2. Irradiation of the Human Body by Cosmic Rays and Natural Radio-Elements

		Dose ($r \times 10^{-3}$ *per year*)	*Type of radiation and distribution of the dose*	
				%
Cosmic rays	Altitude = 0	30	Mesons	75
	Altitude = 4,500m.	150	Electrons	25
Radio-Activity of the Soil	Sedimentary soils	30		
	Granite	120	γ K	32
			γ Th	34
			γ U	34
Radio-Activity of the human body	C^{14}	1.2	β	100
	K^{40}	18	β	80
			γ	20

New atomic centres are, however, constantly being established, and in the near future, hundreds of tons of fissile products will have to be disposed of each year. If these products were released into the atmosphere and into the sea, we should then begin to approach the permissible limit, and the situation would have to be carefully considered, more especially as for the time being only the broad order of magnitude of this limit has been established. It is true that in the meantime radio-biologists and geneticists may have made further discoveries and, in particular, have succeeded in ascertaining the frequency of radio-mutations in some creature closer to man than is the mouse. But even if we attain to full understanding of the mechanism govern-

ing the incidence of mutations and their frequency, we shall still be in doubt as to the subsequent conditions of selection in a human population whose natural genetic evolution has already been modified by medicine and technological progress.

A point emphasized at Geneva was the responsibility of the Specialized Agencies of the United Nations—WHO, FAO, Unesco and ILO. For the problem is no longer one of industrial health, to be dealt with at the national level. The radio-active substances produced by explosions are spread over the entire surface of the globe, and the same may be true of the radio-active waste from atomic centres, if it is disposed of in rivers or in the sea. This lays a collective responsibility on the different nations, since it is the whole population of the earth which would suffer from any repercussions affecting health and social conditions.

The International Committee on Radiological Protection has already done valuable service, but a still greater measure of international co-operation is needed. We must exchange basic knowledge, compare our measuring apparatus and establish standards, prepare maps showing soil radio-activity. And we must train men for duties of surveillance. In this connexion a praiseworthy step has been taken by WHO, which organized an international course on 'Health Physics' at Stockholm in the winter of 1955. UN itself, realizing the important effects of ionizing radiations on the human body, has just set up a scientific committee on which 15 countries are represented. We can therefore look to the future with confidence, on condition that the rules already laid down by the great 'atomic' nations for the disposal of radio-active waste products are obeyed by all, and enforced with increasing rigour as the quantities involved grow larger.

BIOLOGICAL AND MEDICAL ASPECTS OF ATOMIC RADIATIONS

The biological effects of nuclear rays may, however, represent more than a new danger to mankind. They also provide man with a new means of controlling the phenomena of existence.

In medicine, fresh resources have been added to radiotherapy and curietherapy. The treatment of tumours is based on the exceptional radiosensitivity of neoplastic cells, but this is frequently not much greater than that of normal cells, and the dose required to destroy the tumourous cells causes damage to the surrounding healthy tissue, especially when the tumour is deep seated.

Particle accelerators, constructed for the study of nuclear reactions, are now providing medical experts with radiations whose energy amounts to tens of millions—sometimes even to several hundred millions—of electron-volts. These rays penetrate far into the body, shedding only a small proportion of

their energy in the surface tissues or organs. They thus make it possible to irradiate deep-seated lesions without harming the healthy tissue nearer the surface. X-rays and high-energy electrons are already in use in many hospitals, but American scientists showed at Geneva what great things could be expected from heavy particles—they have, for instance, succeeded in carrying out hypophysectomies with the help of protons of 340 Mev and deuterons of 190 Mev.

In telecurietherapy and for insertion and infiltration procedures, cobalt 60, prepared in atomic reactors, is gradually replacing the more costly radium; and visitors to the Geneva exhibition saw apparatus produced in Canada and the U.S.S.R. which uses cobalt sources of the order of 1,000 curies.

Strontium 90, which gives off beta particles, is an excellent source of radiations for the treatment of superficial lesions, especially lesions of the cornea.

The great value of isotopes, however, comes from the fact that they make it possible to insert a source of radiation within the tumour itself. Reliance is sometimes placed on the affinity of certain organs or systems of a particular chemical element, such as the well-known affinity between iodine and the thyroid gland, or phosphorus and the skeleton. Certain disorders and cancers of the thyroid gland can thus be treated with iodine 131, while phosphorus 32, owing to its effect on the bone-marrow, has a favourable influence in some forms of haemopathy, such as polycythemia vera and leucaemia. Affinities of this kind are exceptional, and attempts have been made to prepare chemical substances or antibodies which could be taken up by certain tissues or organs as a result of selective affinity. So far, research on these lines has produced no practical results.

In the absence of physiological localization, there are various ways of introducing the radio-active product into the tumour to be treated. In the case of cavities, such as the pleural or peritoneal cavity, the method chosen is often that of colloidal suspensions of gold, yttrium, chromium phosphate, etc. The choice of particles is determined by the fact that their size must be such that only a negligible quantity of the product will be circulated in the blood, while its passage through the lymphatic system will be untrammelled. Small radio-active granules may also be inserted into a tumour; granules of yttrium have, for instance, been used to destroy hypophysis. Another method is to use thin tubes or strips of nylon, inside which are inserted scraps of thread of gold 148, or radio-active solutions, usually of iodine 131.

Recent research also suggests the possibility of neutrontherapy which would involve introducing into the tumour a strong concentration of lithium 6, boron 10 or uranium 235 and then irradiating it with slow neutrons. Lithium, boron and uranium have a very high effective capturing capacity—in other words, they absorb a considerable proportion of the neutrons and produce

alpha rays and recoil or fission products which destroy the cells of the tumour. Unfortunately it is apparently difficult to obtain a sufficiently strong concentration of these substances to treat the tumour, and experiments with lithium and boron have proved disappointing. On the other hand, the information submitted at Geneva, though incomplete, suggests that the use of uranium 235 might yield better results.

Bacteria are far less sensitive than tumourous cells to the effects of ionizing rays, and can only be destroyed by doses of 100,000 or even 1 million roentgens. Powerful sources of radiation are, however, supplied by the fission products discarded from atomic centres, and it has been suggested that these might be used for sterilizing pharmaceutical products or foodstuffs. This method might, indeed, be valuable in the case, of thermolabile substances, such as the antibiotics, or for those which, like meat, have to be kept at a low temperature. Worms' eggs are easily destroyed, and at Geneva it was demonstrated that the irradiation of foodstuffs can prevent the development of helminthiasis. Administered in such strong doses, however, it sometimes causes chemical changes which may affect flavour or give rise to toxic products, so that supervision is necessary. Considerable protective casing is also required, which makes this method of sterilization costly.

The destruction of living cells by radiation has also been used in preserving certain vegetables, including potatoes. If exposed to a dose of gamma rays of between 10,000 and 20,000 roentgens, the latter will be prevented from sprouting and can be stored for 18 months without losing weight or going soft.

Various ingenious methods of insect pest control were described at Geneva. Among them was the procedure adopted on the island of Curaçao by the United States Department of Agriculture and the Dutch authorities of the island, to exterminate *Callitroga americana,* a species of fly whose larva causes heavy losses of cattle and hides in the United States every year. Laboratory-reared male flies were sterilized by the gamma rays of cobalt 60 and set free in numbers far exceeding the local population of male flies. Female flies mate only once in their lives; most of them met with irradiated males and laid sterile eggs.

Ionizing rays are not used solely for destroying dangerous cells and pests. They also serve to produce mutations. These do not differ qualitatively from natural mutations, but their frequency may be thousands of times greater, making it possible to produce, in a single year, varieties which nature might take several thousand years to develop.

Most radio-mutations, it is true, give rise to varieties with undesirable characteristics, which in the past have been eliminated; but man is guided in his selection by the advantages the new variety presents form his point of view—easy cultivation, rapid growth, high yield, etc.—and this method bears no resemblance to natural selection. Thus, irradiation of the spores of

penicillium mould has produced a mutant which has been selected for its high penicillin yield. The same applies to plants used for fodder, and to cereals. From among the varieties obtained by cross-breeding or irradiation, a selection is made of those best suited to the conditions of modern agriculture —mechanization, intensive use of fertilizers, reduction of manpower, etc. In some countries, for example Sweden, practical results have already been obtained with barley, lupin, white mustard and various other plants. In most cases it is the seeds which are irradiated; but it is also possible—in fruit trees, for instance—to produce somatic mutations by irradiating shoots or young plants. Experiments carried out in Canada have had interesting results, both in improving the quality of fruit and in accelerating the ripening process.

It must be realized, however, that we are at present quite unable to direct these radio-mutations. The most that is possible is to exert a slight influence over them. For instance, Swedish research has shown that, in the case of barley, the percentage of lethal mutants diminishes as the linear ion density increases; if the seed is irradiated with rapid neutrons the percentage of lethal mutants is only half that produced by irradiation with the gamma rays of cobalt. These facts may serve to shed light on the mechanism of radio-genetic action and make it possible to produce the most useful varieties in greater quantity.

CONCLUSIONS

It would have been quite impossible to describe, during the Geneva Conference, the whole vast range of research initiated with the help of tracer isotopes in almost every branch of biology, medicine and agriculture, or even to arrange for the specialists in all these different branches to be adequately represented. The best that could be done was to present a general picture—with omissions and imperfections—which, however faulty and incomplete, was impressive by the variety and extent of the prospects it revealed.

Questions connected with the biological action of ion radiations form a more homogeneous group, for fundamental radio-biology constitutes the scientific basis essential both to the solution of problems of protection and to the further development of medical and agricultural applications.

Now that the nuclear industry is expanding, biologists and doctors are concerned above all with the safety of its workers and of the population in general. Increased power supplies should result in improved living standards, and it would be unfortunate if this gratifying prospect were clouded by fears of a new peril. The nascent nuclear industry is aware of its grave responsibilities. It knows that protection, control and surveillance are costly, but it is ready to accept the burden and is itself contributing to the development of basic research.

It cannot be denied that some danger does exist, event apart from the appalling menace of atomic warfare; but risks are inseparable from any kind of technological progress. Motor traffic is responsible for a heavy death-roll, and the fumes from exhaust pipes, which sometimes contain cancer breeding substances, poison the atmosphere of our cities. Has there been any suggestion of banning motor traffic? Has there been any attempt to assess the long-term risks of radiotherapy or even of repeated X-ray examination?

It is the duty of biologists and doctors to enlighten the public about the nature and gravity of radio-biological repercussions; but it rests with the population as a whole, or with the government which represents it, to fix the limits of the risks which are to be accepted in view of the social importance of these new sources of power.

The danger, however, transcends national frontiers, and the dissemination of radio-active products over the entire surface of the globe makes close international co-operation imperative. The Geneva Conference provided a first opportunity for scientists to exchange views and compare the protective measures enforced in the different countries. The similarity of the solutions adopted encourages us to hope for the conclusion of an international agreement on the peaceful use of atomic energy and on the amount of radio-activity permissible on the earth's surface.

The present maximum doses should suffice for the protection of workers, but the safety of the general population calls for the establishment of safety regulations on a world-wide scale and the institution of effective international control. It also requires the continuation of fundamental radio-biological study to increase our insufficient knowledge regarding the machanism of the biological action of ion radiations.

With a little wisdom and goodwill, the resultant balance will be definitely on the credit side, and mankind will be free to rejoice in the promise of happiness held out by the development of peaceful applications of atomic energy.

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